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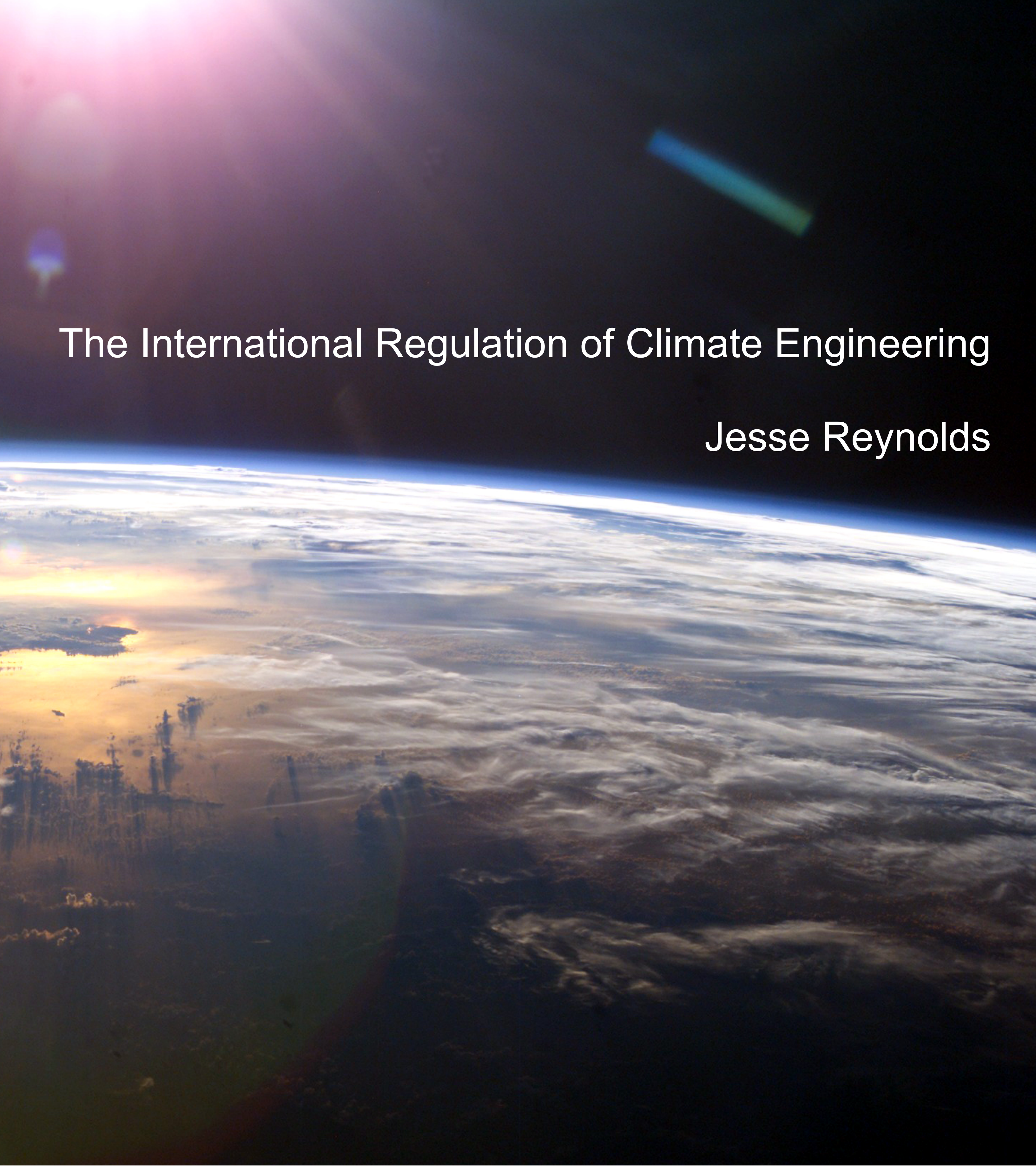

The International Regulation of Climate Engineering

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TILBURG UNIVERSITY

The International Regulation of Climate Engineering

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This work is dedicated to my son, whose birth and particular life journey fundamentally shaped, among innumerable other things, my understandings of wellbeing, the future, and technology.

Copyright

The articles

This dissertation consists of five articles which have been or will be published in refereed academic journals. The author has chosen to retain the formatting, citation style, and pagination of the published articles. Consequently, these aspects appear somewhat inconsistent here.

‘The Regulation of Climate Engineering.’ in *Law, Innovation and Technology* (2011) vol. 3, no. 1, pp. 113–136.

‘Climate Engineering Research: A Precautionary Response to Climate Change?’ coauthored with Floor Fleurke, in *Carbon and Climate Law Review* (2013) no. 2, pp. 101-107.

> *Note*: I was the lead author for the above article. I largely wrote sections I (Introduction), II (Climate Change and Climate Engineering), and III (A *Prima Facie* Case for Climate Engineering Deployment). Dr. Fleurke was responsible for section IV (Precaution). We collaborated on sections V (Precaution and Climate Engineering), VI (United Nations Framework Convention for Climate Change), and VII (Conclusions). My contribution was thus approximately two-thirds.

‘The International Regulation of Climate Engineering: Lessons from Nuclear Power.’ in *Journal of Environmental Law* (2014) vol. 26, no. 2, pp. 269-289.

‘Climate Engineering Field Research: The Favorable Setting of International Environmental Law.’ in *Washington & Lee Journal of Energy, Climate, and the Environment* (2014) vol. 5, no. 2, pp. 417-486.

‘A Critical Examination of Climate Engineering Moral Hazard and Risk Compensation.’ under review.

Contents

The International Regulation of Climate Engineering: Introduction

Presently, anthropogenic climate change is perhaps the greatest environmental threat and is among the most daunting challenges faced by global society. Its economic costs are expected to be a few percent of global economic activity, or on the order of tens of trillions of present-value euro.[1] The world's poor will disproportionately suffer, and the environmental impact will be unprecedented. Indeed, climate change has elements of a 'perfect storm' of a problem. Its primary causes, carbon dioxide emissions from fossil fuel combustion and—to a lesser extent—land use changes, are central to modern human activity and development. The sets of people who have benefitted the most from historical greenhouse gas emissions and of those who are most at risk have little overlap, with the former having relatively great power while the latter are relatively weak or essentially voiceless (ie, future generations). Emissions abatement is a global, transgenerational collective action problem, in which actors generally lack sufficient incentive to take significant action, yet it is in their interests to free ride on others' efforts. Attempts to reduce climate change risk opening other problematic dialogues such as those regarding heterogeneous economic development, historic responsibility of industrialized countries for the relative poverty of the developing ones, and the preferred relationship between humans and the natural environment.

To date, the leading organized effort to reduce climate change risks has been greenhouse gas emissions abatement, which has been largely unsuccessful. Global annual emissions rise almost every year. The leading international vehicle for these efforts, the Kyoto Protocol to the United Nations Framework Convention on Climate Change, appears to have accomplished little.[2] In fact, although those industrialized countries which committed to emissions abatement through the Kyoto Protocol—accounting for only about one-fifth of annual carbon dioxide emissions—

[1] The present-value (ie, discounted) of expected climate damages for the 'no controls' scenario is estimated to be 23 trillion US dollars, or 16 trillion euro. William Nordhaus, *A Question of Balance: Weighing the Options on Global Warming Policies* (Yale University Press 2008) 204.

[2] Kyoto Protocol to the United Nations Framework Convention on Climate Change (adopted 11 December 1997, entered into force 16 February 2005) 2303 UNTS 148. See Quirin Schiermeier, 'Hot Air' (2012) 491 Nature 656.

appear to have collectively met their 2012 targets, this is due largely to two developments which were not driven by climate policy.[3] First, the bulk of the emissions reduction was due to the economic decline of Eastern Europe in the early 1990s and to the global financial crisis of the late 2000s. Second, during this period, much heavy manufacturing migrated from the industrialized countries with Kyoto commitments to developing countries without them—a textbook case of leakage. The prospects of a successor agreement which meaningfully reduces emissions seem slim. For example, Japan (the 7th greatest annual emitter of carbon dioxide), Russia (4th), and Canada (8th) have already declined to participate in an extension of the Kyoto Protocol.[4] China (1st), the US (2nd), India (3rd), Indonesia (5th), Brazil (6th), Mexico (10th), Iran (11th), and South Korea (12th) never committed to Kyoto abatement.

There are several reasons to remain pessimistic about future action to reduce greenhouse gas emissions. First, fossil fuel combustion remains essential to economic activity, and its reduction will carry large costs.[5] It is true that industrialized countries account for the majority of historical emissions, and it is perhaps easy for observers there to see abatement opportunities with low or even negative costs and with little impact on quality of life. However, most current emissions are, and most future emissions will be, from developing countries.[6] This leads to the second reason: countries greatly diverge in their commitments to abatement. In developing countries, widespread access to reliable, affordable energy is presently the only known route to development with its concomitant improvements in living conditions, some aspects of which can be considered as human rights.[7] Understandably, leaders there insist on such development. Third, as described above, abatement is a global transgenerational collective action problem, whose resolution would require each country to undertake costly actions in order to prevent damage throughout the world—including in distant locations—and in the future. Such steps are politically

[3] Emissions data are for 2011 and from World Resources Institute, 'Climate Analysis Indicators Tool (CAIT) 2.0' <http://cait2.wri.org> accessed 16 June 2014. Unlike other datasets, this includes land use change and forestry.

[4] Ibid; 'Kyoto Deal Loses Four Big Nations' *Agence France-Presse* (29 May 2011).

[5] Nordhaus (n 1) estimates that aggressive emissions abatement would cost about 30 trillion present-value US dollars, or 21 trillion euro.

[6] Current emissions from World Resources Institute (n 3); forecasts from International Energy Agency, *World Energy Outlook 2013* (International Energy Agency 2013), ch 2.

[7] Arjun Sengupta, 'On the Theory and Practice of the Right to Development' (2002) 24 Hum Rts Q 837.

unpopular and the temptation to free-ride is great.[8] Fourth, because accumulated carbon dioxide does not significantly leave the atmosphere on human time scales, abatement will only delay a given amount of climate change. Actually avoiding dangerous climate change requires radical, rapid changes in the economy and energy systems, and net negative emissions.[9] Finally, the negative effects of climate change, which potentially could increase political support for action, are delayed by decades relative to the emissions which cause them. Indeed, we have already committed to a significant but unknown magnitude of future climate change, possibly exceeding the agreed-upon threshold of 2°C warming, even if all emissions were to immediately cease.[10] By the time strong negative effects are felt, it will be too late to avoid more extreme damage through abatement.

The second primary category of action to reduce climate change risks has been to adapt society and ecosystems to a changed climate. Although consideration of adaptation lagged behind that of emissions abatement, it is now on almost equal footing in the international discourse, at least rhetorically.[11] The capacity for adaptation is also limited. It is more urgent in developing countries, which are more vulnerable to climate change due to their economies and geographies. Because these countries are poorer and because the wealthy industrialized countries dominate historical emissions, the latter are expected to finance adaption.[12] However, the necessary massive wealth transfers are likely to be politically unpopular in their source countries.

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[8] Although support for action against climate change is popular in isolation, it is low when placed against competing policy objectives. For example, in an annual American survey, 'dealing with global warming' has been last or second-to-last among the 15 to 20 public policy priorities since its inclusion in the 2007 survey. The Pew Research Center for People and the Press, 'Thirteen Years of the Public's Top Priorities' (2013) <http://www.people-press.org/interactives/top-priorities/> accessed 27 May 2014. Similarly, the UN has conducted an online, non-scientific poll which asks respondents for their preferred priorities for the UN. With more than two million responses, 'action taken on climate change' is the bottom of sixteen priorities. United Nations, 'MY World' <http://data.myworld2015.org/> accessed 16 June 2014.

[9] In order to give an idea of the change required, if the climate sensitivity (the warming resulting from a doubling of atmospheric carbon dioxide concentrations) is the estimated 3°C, then keeping warming to the agreed-upon limit of 2°C requires the deployment of 1100 megawatts of carbon-free power generation (about 1.5 times the capacity of a nuclear power plant) every day for fifty years. Ken Caldeira, Atul Jain and Martin Hoffert, 'Climate Sensitivity Uncertainty and the Need for Energy Without CO_2 Emission' (2003) 299 Science 2052. The actual climate sensitivity may be higher. Further, this research is now eleven years old and thus the requirements are now greater.

[10] Myles Allen and others, 'Warming Caused by Cumulative Carbon Emissions towards the Trillionth Tonne' (2009) 458 Nature 1163.

[11] See Roger Pielke, Jr. and others, 'Lifting the Taboo on Adaptation' (2007) 445 Nature 597.

[12] United Nations Framework Convention on Climate Change (UNFCCC) (adopted 9 May 1992, entered into force 21 March 1994) 1771 UNTS 107 art 3.1, 4.4.

Furthermore, there are limits to what adaptation can accomplish, and it can be difficult to distinguish it from traditional development projects. This may tempt leaders of industrialized countries to merely reclassify traditional development aid as adaptation financing, and the total of the two could remain limited. Indeed, international adaptation financing appears to be inadequate, although it is increasing.[13]

It is in this context that some scientists and other observers are increasingly discussing and researching proposed large scale, intentional interventions into global environmental systems in order to counterbalance some effects of climate change. These 'climate engineering' or 'geoengineering' methods are diverse, and there are two primary categories of climate engineering. Carbon dioxide removal (CDR) would remove this most important greenhouse gas from the atmosphere. In general, these methods would be slow and expensive with less potential for negative secondary effects. Solar radiation management (SRM) would reflect a small portion of sunlight away from the earth in order to counteract the warming component of climate change. In general, SRM methods would be relatively fast and inexpensive with greater potential for negative secondary effects. However, even within these categories there is great breadth. For example, both ocean fertilization and large scale afforestation would be considered CDR, and both stratospheric aerosol injection and increased albedo of human-made structures would be SRM.

Climate engineering has been and remains controversial. Indeed, it was essentially taboo prior to 2006, and even now a cloud of suspicion follows the topic.[14] The concerns vary widely, but are grouped here. The first three clusters of concerns are relatively well established in the literature. First, there would be risks to humans and the environment through potential negative secondary effects. Perhaps most importantly, climate change will impact both temperature and precipitation patterns heterogeneously in time and space, while SRM would counter each

[13] Muyeye Chambwera and others, 'Economics of Adaptation' in Intergovernmental Panel on Climate Change Working Group II, *Climate Change 2014: Impacts, Adaptation, and Vulnerability* (Cambridge University Press 2014); UNFCCC, *Report of the Conference of the Parties on its Sixteenth Session, Held in Cancun from 29 November to 10 December 2010* (FCCC/CP/2010/7/Add1, Decision 1/CP16, 2011) which established a Green Climate Fund.

[14] Paul Crutzen, 'Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?' (2006) 77 Clim Change 211; Mark Lawrence, 'The Geoengineering Dilemma: To Speak or not to Speak' (2006) 77 Clim Change 245.

imperfectly.[15] Thus, regardless of the latter's optimization, warm, cool, dry, and wet places would remain. SRM would also alter sunlight, making it more diffuse with uncertain impacts on ecosystems and agriculture.[16] Furthermore, interventions such as ocean fertilization would alter marine ecosystems.[17] Some CDR methods would require massive land-use changes, and stored carbon dioxide could leak.[18] A leading candidate for stratospheric aerosol injection, sulphur dioxide, could damage the ozone layer.[19] Most likely, some climate engineering methods would bring with them still-unknown secondary effects. A second cluster of concerns is the political and social challenges. Many observers believe that discussion, research, and development of climate engineering would reduce the political willpower and incentives for the preferred responses of emissions abatement and adaptation.[20] Some are worried that such activity now would bias later decision-making toward implementation through 'technological momentum,' 'lock-in,' and the establishment of influential vested interests.[21] Others focus on implementation scenarios, arguing that disagreement over the planet's climate will escalate international tensions and that the practice is ungovernable without autocracy.[22] Another fear is that, once started, SRM would need to be maintained for a very long time, and that its cessation would cause rapid climate change and severe harm.[23] The ability to alter the climate, and especially the exclusive means to do so through intellectual property claims, for example, might alter and exacerbate power relations among states, international institutions, people, corporations, and other actors.[24] The third cluster

[15] Ben Kravitz and others, 'A Multi-Model Assessment of Regional Climate Disparities Caused by Solar Geoengineering' (2014) 9 Envtl Res Lett 074013.

[16] Lili Xia and others, 'Solar Radiation Management Impacts on Agriculture in China: A Case Study in the Geoengineering Model Intercomparison Project (GeoMIP)' (2014) 119 J Geophys Res Atmos 8695.

[17] Phillip Williamson and others, 'Ocean Fertilization for Geoengineering: A Review of Effectiveness, Environmental Impacts and Emerging Governance' (2012) 90 Proc Safety Envtl Prot 475.

[18] Klaus Lackner and others, 'The Urgency of the Development of CO_2 Capture from Ambient Air' (2012) 109 Proc Nat Acad Sci 13156.

[19] Giovanni Pitari and others, 'Stratospheric Ozone Response to Sulfate Geoengineering: Results from the Geoengineering Model Intercomparison Project (GeoMIP)' 119 J Geophys Res Atmos 2629.

[20] Albert Lin, 'Does Geoengineering Present a Moral Hazard?' 40 Ecol LQ 673.

[21] Dale Jamieson, 'Ethics and Intentional Climate Change' (1996) 33 Clim Change 323.

[22] Bronislaw Szerszynski and others, 'Why Solar Radiation Management Geoengineering and Democracy Won't Mix' (2013) 45 Env Plan A 2809.

[23] Marlos Goes, Nancy Tuana and Klaus Keller, 'The Economics (or Lack Thereof) of Aerosol Geoengineering' (2011) 109 Clim Change 719.

[24] Anthony Chavez, 'Exclusive Rights to Saving the Planet: The Patenting of Geoengineering Inventions' Northwest J Tech Intell Prop (forthcoming).

of concerns is ethics.[25] Some writers assert that developing and implementing climate engineering would be unjust, both across generations and among groups within current generations.[26] Some people may be harmed, and it remains unclear whether and how they could be compensated.[27] One could also argue that some form of consent would be necessary in order to proceed with climate engineering field research or implementation.[28] Others assert that climate engineering would be hubristic, that it would be contrary to appropriate human-nature relationships, that it fails to address the root cause of climate change, or that it merely replicates the same mindset of technical domination of nature which has caused environmental problems in the first place.[29]

Three other clusters of concerns regarding climate engineering are somewhat speculative but I believe that they underlie a significant portion of its controversy. First, the prospect of trying to intentionally manipulate the climate raises deep-seated anxieties in most people. Specifically, studies of risk perception have indicated that laypeople strongly fear risks which are outside their control, potentially widespread, involuntary, unfamiliar, and invisible.[30] Climate engineering fits these characteristics well. Second, climate engineering runs contrary to the norms held by many environmentalists, which constitute a large portion of the voices active in the climate change discourse. For example, cultural theory posits that people generally organize their understanding of the world in one of four (or sometimes five) worldviews, each with its related understanding of nature.[31] Much of the 'deeper' or 'green' environmentalism is built upon an egalitarian worldview, with the understanding that nature is ephemeral.[32] Yet these egalitarians are also generally averse to large-scale technological endeavours. Consequently, environmentalists who might otherwise be supportive of an additional means to reduce risks from

[25] For a review, see Christopher Preston, 'Ethics and Geoengineering: Reviewing the Moral Issues Raised by Solar Radiation Management and Carbon Dioxide Removal' (2012) 4 WIREs Clim Change 23.

[26] Toby Svoboda and others, 'Sulfate Aerosol Geoengineering: The Question of Justice' (2011) 25 Pub Aff Q 157.

[27] Toby Svoboda and Peter Irvine, 'Ethical and Technical Challenges in Compensating for Harm Due to Solar Radiation Management Geoengineering' (2014) 17 Ethics Pol'y Env 157.

[28] David Morrow, Robert Kopp and Michael Oppenheimer, 'Toward Ethical Norms and Institutions for Climate Engineering Research' (2009) 4 Envtl Res Lett 045106.

[29] Clive Hamilton, *Earthmasters: The Dawn of the Age of Climate Engineering* (Yale University Press 2013).

[30] Paul Slovic, Baruch Fischhoff and Sarah Lichtenstein, 'Behavioral Decision Theory Perspectives on Risk and Safety' (1984) 56 Acta Psychologica 183.

[31] Michael Thompson, Richard Ellis and Aaron Wildavsky, *Cultural Theory* (Westview Press 1990).

[32] Karl Dake, 'Orienting Dispositions in the Perception of Risk' (1991) 22 J Cross-Cult Psych 61.

climate change are often opposed to climate engineering.[33] Finally, climate change has become such a prominent and difficult debate in part because it is fundamentally linked to several other issues with high stakes and strong opinions. In this, many of the supporters for action against climate change foresee other benefits concomitant with emissions abatement and adaptation. Environmentalists, particularly those of the 'deeper green' variety, may expect broader deindustrialization and generally reduced environmental impacts with aggressive emissions abatement. Similarly, advocates of global justice and economic development may expect significant international wealth transfers from industrialized countries to developing ones through adaptation funding and through certain abatement mechanisms, such as carbon markets with joint implementation and a clean development mechanism. Thus, from a more politically pragmatic perspective, in their eyes climate engineering might be able to reduce the risks of climate change while, to the extent that it might decrease abatement and adaptation, failing to deliver these concomitant benefits. This likely further undermines support among constituencies who may otherwise seek to reduce climate risks.

Although almost no climate engineering advocates are presently calling for implementation, research itself raises some risk of negative secondary effects. Scientists will soon wish to test these methods in the field. Particularly in the case of SRM, they would eventually need experiments of sufficient space, time, and intensity in order to detect the test's signal amid the noise of the weather.[34] This sort of research is unprecedented, and some form of regulation appears to be justified in order to balance potential benefits with risks. Furthermore, these effects—during both research and implementation, both intended and secondary, and both beneficial and harmful—would take place across national borders and in areas outside of state control. Regulation thus becomes an international matter. Yet no multilateral environmental agreements directly address climate engineering, although some would be applicable.

1. QUESTION AND APPROACH

This dissertation examines the international regulation of climate engineering. Specifically, considering the proposed technologies, the suggested research toward them, extant

[33] Clare Heyward and Steve Rayner, 'Apocalypse Nicked!' (2013) *Climate Geoengineering Governance Working Paper Series* 6 < http://www.geoengineering-governance-research.org/cgg-working-papers.php> accessed 12 August 2014.

[34] Douglas MacMynowski and others, 'Can We Test Geoengineering?' (2011) 4 Energy Environ Sci 5044.

law, and the political context, to what degree could existing and feasible international regulation minimize the risks from climate engineering while allowing it to develop in order to reduce risks from climate change? The work herein focuses primarily on climate engineering research and particularly on the more highly leveraged proposals such as stratospheric aerosol injection and marine cloud brightening. It does so in both positive (asking, for example, what is the existing international regulation?) and normative (asking, for example, what should the international regulation be?) manners. However, because the dissertation consists of five separate essays which have been or will be published as articles in refereed academic journals, it does not systematically address this broad question but instead examines a handful of specific aspects, striving to contribute distinct parts to a larger picture.

Furthermore, the five articles do not possess a discrete methodology, but do share a general approach to their particular questions. First of all, because regulation is usually legal in its character, this research project is centred in law, and specifically in international environmental law. Although definitions vary, here law refers to formal systems of norms and rules which are developed, promulgated, monitored, and/or enforced by authoritative institutions in order to intentionally guide behaviour and to prevent and resolve conflicts. States are the central—but not the sole—actors in law. Because states' existence is based upon sovereignty, national law differs fundamentally from international law. Within states, there are typically clear constitutional means for the production and revision of law, a hierarchy of authority, and enforcement backed by the threat of force. However, beyond the state there is no such hierarchical authority and states are mutual peers.[35] In that domain, states voluntarily make commitments to one another though means including explicit legal instruments, customary law, and principles—together constituting international law.

The emphasis throughout is on the logic of consequences. This may stand in contrast to the bulk of international legal scholarship, which focuses instead upon the logic of appropriateness. This is not to imply exclusive attention to the former at the expense of the latter, nor that the latter is unimportant; only that I am more interested in what would be effective and feasible relative to what is normatively preferable from a legal perspective. As such, the research here draws from three related fields, although these are more like shadows in the background than overtly employed methodologies.

[35] The European Union is a notable exception.

The first such 'methodological shadow' is political science. As the study of how and why societies make collective decisions, political science is closely related to law and clearly relevant when asking what may be feasible. Although cross-fertilization between the fields has a long history in the domestic context, such connections in the international domain have proven more challenging. International political science has generally taken the form of international relations, which examines interactions among states. Specifically, the institutionalist view asserts that states are the dominant (but not sole) actors in international relations, that they have varying interests and capabilities, that they rationally pursue those interests, and that they seek absolute gains. To that end, states sometimes cooperate in order to share information, to lower transaction costs, to coordinate, and to address collective action problems. Such cooperation can lead to diverse agreements, which vary in the degree of legalization and which can be expanded into regimes: 'principles, norms, rules, and decision-making procedures around which actor expectations converge in a given issue-area.'[36] Although the violation of agreements can be costly due to reciprocation, retaliation, and reputational loss, it can sometimes still be rational and beneficial.[37]

The second 'methodological shadow' is economics. Many of the most difficult questions concerning climate change and climate engineering present challenging trade-offs. For example, climate engineering and its research may reduce the risks from climate change yet pose risks of their own. The difficulty presented in this is central to how international law may respond to climate engineering. Economics attempts to rationally explore how people—individually and collectively—use limited resources to pursue competing goals and can thus assist in such a balancing. The field's tools can provide the basis for benefit-cost analysis of both possible responses to climate change and regulatory options. This analysis will be particularly difficult in the case of climate engineering, for several reasons. First, knowledge of possible outcomes and their probability will both remain problematic.[38] Second, decisions concerning climate engineering are not simply an expense versus a benefit but often constitute a risk-risk trade-off in

[36] Stephen Krasner, 'Structural Causes and Regime Consequences: Regimes as Intervening Variables' (1982) 36 Int Organ 185, 185.

[37] Andrew Guzman, *How International Law Works: A Rational Choice Theory* (OUP 2008).

[38] Stirling would call this ignorance. Andrew Stirling, 'Risk at a Turning Point?' (1998) 1 J Risk Res 97;

which risks can be transformed in terms of their affected population and their type.[39] Third, the expected damage of climate change and climate engineering each have long-tail probability distributions, in that there are small chances of very high damages.[40] Despite these challenges, society must make decisions, and a rational weighing of advantages and disadvantages remains a superior (but by no means the sole) basis of decision making.[41] This will not be simple work which will provide clear answers, and I do not purport to conduct it here. However, the existence of rational weighing underlies the economic analysis of law in general and the papers here specifically.

Finally, this is an example of the regulation of new technologies. To some degree, some of the questions posed by climate engineering are not fully novel.[42] Several scholars have offered general suggestions for how law and regulation can address powerful new technologies.[43] Clearly, when new technologies pose risks of negative external effects—to human health, to institutions, to the environment, or to widely held values and interests—then regulation may be warranted. However, new technologies can be unlike other regulated activities in questions of scale, uncertainty, complexity, and the speed of innovation.[44] Yet the relationship between law and technology can be reciprocal. For example, a new technology can alter the cost of violating and/or enforcing laws, the facts which previously justified laws, or the underlying justifications for legal concepts and categories.[45]

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[39] John Graham and Jonathan Baert Wiener, 'Confronting Risk Tradeoffs' in John Graham and Jonathan Baert Wiener (eds), *Risk vs Risk: Tradeoffs in Protecting Health and the Environment* (Harvard University Press 1995) 19-41

[40] Richard Posner, *Catastrophe: Risk and Response* (Oxford University Press 2004). See also Cass Sunstein, *Worst-Case Scenarios* (Harvard University Press 2007).

[41] See Richard Revesz and Michael Livermore, *Retaking Rationality: How Cost-Benefit Analysis Can Better Protect the Environment and Our Health* (Oxford University Press 2011).

[42] Already in 1982, Douglas and Wildavsky noted that, 'Once the source of safety, science and technology have become the source of risk.' Mary Douglas and Aaron Wildavsky, *Risk and Culture: An Essay on the Selection of Technical and Environmental Dangers* (University of California Press 1982) 10.

[43] See Arthur Cockfield, 'Towards a Law and Technology Theory' (2004) 30 Manitoba L J 383; Roger Brownsword and Han Somsen, 'Law, Innovation and Technology: Before We Fast Forward, A Forum for Debate' (2009) 1 L Innov & Tech 1; Gregory Mandel, 'Regulating Emerging Technologies' (2009) 1 L Innov & Tech 75.

[44] Floor Fleurke & Han Somsen, 'Precautionary Regulation of Chemical Risk: How REACH Confronts the Regulatory Challenges of Scale, Uncertainty, Complexity and Innovation' (2011) 48 CML Rev 357.

[45] David Friedman, 'Does Technology Require New Law?' (2001) 25 Harv JL & Pub Pol'y 71. See also Lyria Bennett Moses, 'Recurring Dilemmas: The Law's Race to Keep up with Technological Change' (2007) 2007 U Ill JL Tech & Pol'y 239.

2. THE ARTICLES

The first article, 'The Regulation of Climate Engineering,' provides an initial exploration of the challenges raised by climate engineering and its research. It argues that regulation is indeed justified, and that SRM versus CDR and research versus implementation should each be kept distinct. It concludes that innovative regulatory approaches hold significant potential for this goal.

The second article, 'Climate Engineering Research: A Precautionary Response to Climate Change?', co-authored with Floor Fleurke, explores how the precautionary principle could be applied to climate engineering. We make a case that, prima facie, climate engineering may provide means to reduce climate risks, and conclude that precaution encourages moderate scale climate engineering field tests, despite potential risks.

The third article, 'Climate Engineering Field Research: The Favorable Setting of International Environmental Law,' examines the relevant existing international environmental law. The approach here is distinct in that it distinguishes between climate engineering research and implementation, and emphasizes both the climate change context of these proposals and the enabling function of law. It concludes that extant international environmental law generally favours climate engineering field tests, in large part because, even though field trials may present risks to humans and the environment, climate engineering may reduce the greater risks of climate change. Notably, this favourable legal setting is present in those multilateral environmental agreements whose subject matter is closest to climate engineering.

The fourth article, 'The International Regulation of Climate Engineering: Lessons from Nuclear Power,' looks to climate engineering's closest existing analogy—nuclear power—for lessons, and from this concludes that climate engineering research will be promoted and will not be the subject of a comprehensive binding multilateral agreement in the near future. Instead, climate engineering and its research will more likely be internationally regulated gradually, with an initially low degree of legalization, and through a plurality of means and institutions.

The final article, 'A Critical Examination of Climate Engineering Moral Hazard and Risk Compensation,' critically examines the widespread concern that consideration, research, and development of climate engineering would reduce greenhouse gas abatement and adaptation. After examining this concern from three vantages, the paper concludes that this concern appears to be overstated, and it should not play a central role in climate engineering policy.

Finally, the brief conclusion makes some recommendations toward the international regulation of climate engineering research. It proposes the further development of norms, an international institution, a compensation mechanism, and a non-proliferation agreement.

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Jesse Reynolds

ABSTRACT

Intentional interventions in global physical, chemical, and biological systems on a massive scale are receiving increasing attention in hopes of reducing the threat of anthropogenic climate change. Known as climate engineering, or geoengineering, research is moving forward, but regulation remains inadequate, due in part to significant regulatory challenges. This essay asserts that key to overcoming these regulatory challenges is distinguishing between the two primary forms of climate engineering, and between deployment and research. One of climate engineering's two primary forms, carbon dioxide removal, can largely be addressed through existing legal instruments. In the case of solar radiation management, the other primary form, focusing initially on research can bypass the geopolitical quagmire of deployment. Two other major challenges to developing regulation for solar radiation management research remain: establishing regulatory legitimacy, and developing an appropriate definition of research. Potential regulatory forms include centralized international legal instruments, fully or partially private transnational networks, and norms developed from the bottom up.

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Jesse Reynolds*

INTRODUCTION

Among the greatest challenges faced by society today is the threat of anthropogenic climate change. Its economic costs alone could be 5 to 20 per cent of global production.[1] These costs will be disproportionately borne by the world's vulnerable populations. In addition, there will be non-economic costs, such as human suffering and loss of biodiversity.[2] Estimates of the likely impact of climate change have become increasingly dire.[3]

Unfortunately, there is little reason for optimism. Atmospheric concentrations of greenhouse gases, the cause of anthropogenic climate change, continue to rise.[4] Models which extrapolate current activities estimate that average global warming will double the oft-cited 2°C target limit by the end of the century.[5] International agreements to reduce

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1 Nicholas Stern, *The Economics of Climate Change: The Stern Review* (HM Treasury, 2006) is generally considered the most comprehensive economic analysis of climate change.

2 See eg Chris D Thomas *et al*, 'Extinction Risk from Climate Change' (2004) 427 *Nature* 145.

3 Compare conclusions of the four Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC), issued in 1990, 1995, 2001 and 2007.

4 For recent concentrations see TJ Blasing, 'Recent Greenhouse Gas Concentrations' (Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, updated February 2011), http://cdiac.ornl.gov/pns/current_ghg.html (accessed 7 June 2011). Annual greenhouse gas emissions are generally rising. Jos GJ Olivier and JAHW Peters, *No Growth in Total Global CO_2 Emissions in 2009* (Netherlands Environmental Assessment Agency (PBL), 2010); International Energy Agency, 'Prospect of Limiting the Global Increase in Temperature to 2°C is Getting Bleaker' (30 May 2011), www.iea.org/index_info.asp?id=1959 (accessed 9 June 2011).

5 According to the most recent IPCC Assessment Report, the projected global average surface warming at the end of the 21st century in the A1FI scenario (an integrated world with rapid economic growth and a continued reliance upon fossil fuels) is 4°C. Working Group I of the Intergovernmental Panel on Climate Change, 'Summary for Policymakers' in Susan Solomon *et al* (eds), *Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2007); Working Group III of the Intergovernmental Panel on Climate Change, 'Summary for Policymakers' in Nebojsa Nakicenovic and Rob Swart (eds), *Emissions Scenarios* (Cambridge University Press, 2000). The 2°C limit was adopted in the non-binding Copenhagen Accord at the 2009 Conference of Parties to the UN Framework Convention on Climate Change (1992). It

greenhouse gas emissions have had limited results.[6] These efforts face difficult problems not only of coordination, collective action and free-riding, but also of global and intergenerational equity and justice.[7]

In response to the risks of climate change, academics and policymakers have considered increasingly drastic measures. For example, advocates of reducing greenhouse gas emissions were originally concerned that their efforts would be undermined by public discussion of adapting society to a different climate. Now, however, both emissions reductions and adaptation are generally considered to be the two pillars of effective climate change policy.[8]

A third potential set of responses to the threat of climate change is increasingly entering public debate. Climate engineering, or geoengineering,[9] is a group of proposals to intentionally intervene in global physical, chemical and biological systems on a massive scale in order to reduce the threat of anthropogenic climate change. These proposals carry their own risks and have been controversial and, until recently, open discussion of climate engineering has been limited.

Although there is near unanimous agreement that deployment of climate engineering should be regulated, there is wide variation as to whether regulation is feasible and, if so, how it should be done. Various authors have ranged from concluding that climate engineering will inevitably be prohibited[10] to arguing that it cannot be controlled.[11]

had been the consensus of industrialised countries, but was recently challenged by leaders of various developing nations who called for a lower limit. For a history of the limit see Michael Oppenheimer and Annie Petsonk, 'Article 2 of the UNFCCC: Historical Origins, Recent Interpretations' (2005) 73 *Climatic Change* 195; Chris Shaw, 'The Dangerous Limits of Dangerous Limits: Climate Change and the Precautionary Principle' (2009) 57 *Sociological Review* 103.

6 The Kyoto Protocol (1997) to the UN Framework Convention on Climate Change (UNFCCC) is the primary international agreement relating to reductions in greenhouse gas emissions. The countries not bound by the Protocol include three of the top four emitters (China, the USA and India) and account for approximately 70% of emissions (2008 data in International Energy Agency, *CO_2 Emissions from Fuel Combustion 2010: Highlights* (IEA, 2010)). Although the countries that are bound by it are on track to collectively meet the 2012 target, much of this emissions reduction is due to decreased economic activity, in Russia and Eastern Europe in the 1990s and throughout the globe in more recent years. See Olivier and Peters (n 4). The Protocol expires at the end of 2012 and no successor is apparent.

7 See eg Stephen M Gardiner, 'Ethics and Climate Change: An Introduction' (2010) 1 *Wiley Interdisciplinary Reviews: Climatic Change* 54.

8 See eg Roger Pielke *et al*, 'Climate Change 2007: Lifting the Taboo on Adaptation' (2007) 445 *Nature* 597.

9 Although 'geoengineering' is more common, the term 'climate engineering' is increasingly used because of its greater accuracy and to avoid confusion with geoengineering in the context of civil engineering.

10 William Daniel Davis, 'What Does "Green" Mean?: Anthropogenic Climate Change, Geoengineering, and International Environmental Law' (2009) 43 *Georgia Law Review* 901.

11 '[I]t may be impossible for countries to keep a commitment to abstain from experimenting with geoengineering. The incentives for countries to reduce emissions on a substantial scale are too weak, and the incentives for them to develop geoengineering are too strong, for commitment to be a realistic prospect. Indeed, these two incentives combined are so powerful that many countries may be prepared to develop and deploy geoengineering unilaterally.' Scott Barrett, 'The Incredible Economics of Geoengineering' (2008) 39 *Environmental and Resource Economics* 45, 46.

Elected lawmakers appear reluctant to address it, and an earlier attempt at self-regulation stumbled.[12] A new effort, the Solar Radiation Management Governance Initiative, seeks to tackle this problem by focusing on only one of the two main categories of climate engineering, and on only matters of research, not of deployment. Will this approach help or hinder the initiative in the attempt to surmount some of the regulatory challenges presented by climate engineering?

This essay seeks to answer this question by exploring climate engineering and its regulatory challenges. Part I introduces the history and proposed forms of climate engineering, in particular distinguishing its two primary categories. Part II provides an overview of various international legal instruments that may be relevant to climate engineering, and concludes that one of the two primary forms is largely addressed by existing legal instruments. Part III describes how climate engineering's technical, environmental and political characteristics engender regulatory challenges, which are mostly distinct between its two primary forms. Part IV explores the logic and legal basis of regulation of scientific research, in general, and the implications for the regulation of climate engineering research. Part V highlights specific strengths of and challenges to the Solar Radiation Management Governance Initiative, focusing on legitimacy and the definition of research. Part VI offers a brief concluding summary.

I. AN INTRODUCTION TO CLIMATE ENGINEERING

The consideration of climate engineering is historically intertwined with the awareness of anthropogenic climate change. Soon after Svante Arrhenius proposed that industrial emissions of carbon dioxide may warm the climate, his 'good friend' Nils Ekholm proposed that such emissions would be beneficial, and could be increased.[13] The first government report on the threat of anthropogenic climate change, submitted to US President Lyndon Johnson in 1965, recommended increasing the earth's reflectivity by using buoyant ocean particles, yet it did not consider reducing fossil fuel consumption.[14] In 1977, leading Soviet climatologist Mikhail Budyko proposed what remains the most widely discussed climate engineering method: injecting aerosols into the stratosphere.[15]

12 The Asilomar International Conference on Climate Intervention Technologies is described below, at text to nn 102–6.

13 Svante Arrhenius, 'On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground' (1896) 41 *Philosophical Magazine and Journal of Science* 237; Nils Ekholm, 'On the Variations of the Climate of the Geological and Historical Past and their Causes' (1901) 27 *Quarterly Journal of the Royal Meteorological Society* 1; Svante Arrhenius, *Worlds in the Making: The Evolution of the Universe* (Harper, 1908).

14 President's Science Advisory Committee, *Restoring the Quality of Our Environment* (1965).

15 Mikhail Budyko proposed sulfate aerosols. Mikhail I Budyko, *Climatic Changes* (American Geophysical Union, 1977). Recent research indicates that sulfate may not be ideal, and some scientists propose engineered nanoparticles. David W Keith, 'Photophoretic Levitation of Engineered Aerosols for Geoengineering' (2010) 107 *Proceedings of the National Academy of Sciences* 16428.

The term 'geoengineering' was coined soon thereafter, in the context of deep ocean storage of carbon dioxide.[16] A 1992 major climate change report from the US National Academies included a chapter on climate engineering.[17] By the next decade, an internal US government white paper had suggested a $64 million climate engineering research initiative, but the White House rejected this on political grounds.[18]

The academic and public debates about climate engineering have grown dramatically in the last five years.[19] The breakthrough was a pair of editorials in 2006 by atmospheric chemists, one a Nobel Laureate and the other the president of the US National Academy of Science.[20] In the last two years, the UK Royal Society, the US National Research Council, the UK Institution of Mechanical Engineers, and committees of the UK Parliament and the US Congress issued reports, and the American Meteorological Society and the American Geophysical Union released statements, all of which called for climate engineering research.[21] Recently, modest research projects began to receive funds, both publicly, from the European Union and the United Kingdom, and privately, from billionaires Bill Gates and Richard Branson.[22] The leading body responsible for assessing climate change

16 Cesare Marchetti, 'On Geoengineering and the CO_2 Problem' (1977) 1 *Climatic Change* 59.

17 Committee on Science, Engineering and Public Policy, *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base* (National Academies Press, 1992).

18 Ehsan Khan *et al*, *Response Options to Limit Rapid or Severe Climate Change: Assessment of Research Needs* (2001); Michael MacCracken, 'Geoengineering: Worthy of Cautious Evaluation?' (2006) 77 *Climatic Change* 235; Eli Kintisch, *Hack the Planet: Science's Best Hope—or Worst Nightmare—for Averting Climate Catastrophe* (John Wiley & Sons, 2010) 197–9.

19 For example, in 2009 and 2010 the per annum references in academic literature were approximately 10 times greater than those during the period 1992–2005. See the graph in 'Lift-Off' *The Economist*, 4 November 2010.

20 Paul Crutzen, 'Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?' (2006) 77 *Climatic Change* 211; Ralph Cicerone, 'Geoengineering: Encouraging Research and Overseeing Implementation' (2006) 77 *Climatic Change* 221.

21 Royal Society, *Geoengineering the Climate: Science, Governance and Uncertainty* (2009); America's Climate Choices: Panel on Advancing the Science of Climate Change, *Advancing the Science of Climate Change* (National Academies Press, 2010); Institution of Mechanical Engineers, *Geo-Engineering: Giving Us the Time to Act?* (2009); Science and Technology Committee, *The Regulation of Geoengineering* (HC 2009–10); Rep Bart Gordon, *Engineering the Climate: Research Needs and Strategies for International Collaboration* (2010); American Meteorological Society Council, *AMS Policy Statement on Geoengineering the Climate System* (2009); American Geophysical Union Council, *Position Statement: Geoengineering the Climate System* (2009).

22 'Implications and Risks of Engineering Solar Radiation to Limit Climate Change', http://implicc.zmaw.de (accessed 7 June 2011). The National Environment Research Council and the Engineering and Physical Sciences Research Councils supported a public dialogue on geoengineering and are now funding two multi-university research teams. NERC Public Dialogue on Geoengineering Steering Group, *Experiment Earth? Report on a Public Dialogue on Geoengineering* (2010); 'Integrated Assessment of Geoengineering Proposals', http://iagp.ac.uk (accessed 7 June 2011); Engineering and Physical Sciences Research Council, 'Details of Grant Ep/I01473x/1' (19 November 2010), http://gow.epsrc.ac.uk/ViewGrant.aspx?GrantRef=EP/I01473X/1 (accessed 7 June 2011); 'Fund for Innovative Climate and Energy Research', http://people.ucalgary.ca/~keith/FICER.html (accessed 7 June 2011); Eli Kintisch, 'Bill Gates Funding Geoengineering Research' *ScienceInsider*, 26 January 2010, http://news.sciencemag.org/scienceinsider/2010/01/bill-gates-fund.html (accessed 7 June 2011). Branson offered a reward, not traditional research funding. James Kanter, 'Cash Prize for Environ-mental Help Goes Unawarded' *New York Times*, 21 November 2010.

information, the Intergovernmental Panel on Climate Change, will consider climate engineering to a significant degree in its next Assessment Report.[23]

Forms of Climate Engineering

Climate engineering schemes vary significantly in their goals, means, feasibility, costs, time scales of response, and potential environmental consequences, and are divided into two primary categories.[24] The first, *carbon dioxide removal* (CDR), would collect and sequester this leading greenhouse gas from the atmosphere. Proposals include capturing carbon dioxide from ambient air, fertilising oceans to increase biological uptake, and enhanced mineral weathering.[25] CDR would address the threat of climate change relatively close to its cause, but would be expensive and slow. Therefore, CDR could be a longer-term component in a portfolio of responses to anthropogenic climate change. Most proposed CDR methods would have environmental risks which can be assessed and managed fairly well; a significant exception is ocean fertilisation.

The second form of climate engineering is *solar radiation management* (SRM), which would essentially increase the planet's reflectiveness and thus counteract warming. Proposed methods include injecting aerosols into the upper atmosphere, spraying seawater to increase the brightness of clouds, and injecting microbubbles into the ocean.[26]

23 Alister Doyle, 'Futuristic Climate Schemes to Get UN Hearing' *Reuters*, 27 October 2010; Co-Chairs of Working Groups I, II and III, *Proposal for an IPCC Expert Meeting on Geoengineering* (Intergovernmental Panel on Climate Change, 2010). Three previous Assessment Reports briefly touched upon climate engineering: Rik Leemans *et al*, 'Mitigation: Cross-Sectoral and Other Issues' in Robert T Watson, MC Zinyowera and Richard H Moss (eds), *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses: Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 1995) 811–13; Pekka Kauppi *et al*, 'Technological and Economic Potential of Options to Enhance, Maintain, and Manage Biological Carbon Reservoirs and Geo-Engineering' in Bert Metz *et al* (eds), *Climate Change 2001: Mitigation: Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2001) 332–4; Terry Barker *et al*, 'Mitigation from a Cross-Sectoral Perspective' in Bert Metz *et al* (eds), *Climate Change 2007: Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2007) 624–5.

24 The Royal Society's *Geoengineering the Climate* (n 21) is the most comprehensive and accessible overview of climate engineering methods. A more recent and technical review is Naomi E Vaughan and Timothy M Lenton, 'A Review of Climate Geoengineering Proposals' (2011) *Climatic Change* (forthcoming); published online 22 March 2011 at http://dx.doi.org/10.1007/s10584-011-0027-7.

25 See eg David W Keith, 'Why Capture CO_2 from the Atmosphere?' (2009) 325 *Science* 1654; Ken O Buesseler *et al*, 'Ocean Iron Fertilization—Moving Forward in a Sea of Uncertainty' (2008) 319 *Science* 162; Peter Köhler, Jens Hartmann and Dieter A Wolf-Gladrow, 'Geoengineering Potential of Artificially Enhanced Silicate Weathering of Olivine' (2010) 107 *Proceedings of the National Academy of Sciences* 20228.

26 See eg Crutzen (n 20); John Latham *et al*, 'Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds' (2008) 366 *Philosophical Transactions of the Royal Society A* 3969; Russell Seitz, 'Bright Water: Hydrosols, Water Conservation and Climate Change' (2011) 105 *Climatic Change* 365.

In contrast to CDR, these schemes are estimated to be inexpensive and rapid.[27] For example, the economic costs of stratospheric aerosol injection may be as little as 1 per cent of those of emissions reductions—a characteristic which has been called 'incredible'.[28] However, SRM would address only the warming aspect of climate change and altered atmospheric composition. Other manifestations, such as ocean acidification, would continue.[29] Furthermore, SRM would have significant and unpredictable negative environmental effects. Precipitation patterns would likely change, potentially including a reduction in tropical precipitation, upon which billions rely for agriculture.[30] Incoming light would be more diffuse, increasing primary plant productivity and altering ecosystems.[31] The El Niño/La Niña-Southern Oscillation, a major global climate pattern, may be altered.[32] Sulfate particles, the most widely discussed candidate for injection into the stratosphere, may damage the ozone layer.[33] Because of these characteristics, SRM is more often suggested as a potential (1) medium-term method to minimise the effects of climate change as society transitions to low carbon systems and as greenhouse gas concentrations are reduced, and/or (2) response to abrupt climate change.[34]

II. CURRENT RELEVANT INTERNATIONAL LEGAL INSTRUMENTS

Building on the foregoing introduction to climate engineering, this part reviews some relevant international legal instruments.[35] Although no such international agreements directly address climate engineering, some have applicable provisions whose relevance

27 Estimates of the economic cost of stratospheric sulfate injection are generally between a few billion (eg William D Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming* (MIT Press, 2003)) and 50 billion (eg Crutzen (n 20)) US dollars per year. In their modelling, Nordhaus and Boyer consider this to be so low as to be essentially costless.

28 'The economics of geoengineering are—there is no better word for it—incredible.' Barrett (n 11) 49.

29 '[B]iological communities under acidified seawater conditions are less diverse and calcifying species absent … Ocean acidification is irreversible on timescales of at least tens of thousands of years.' Secretariat of the Convention on Biological Diversity, *Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity*, Technical Series No 46 (Secretariat of the Convention on Biological Diversity, 2009) 9.

30 Alan Robock, Luke Oman and Georgiy L Stenchikov, 'Regional Climate Responses to Geoengineering with Tropical and Arctic SO_2 Injections' (2008) 113 *Journal of Geophysical Research* D16101; Gabriele C Hegerl and Susan Solomon, 'Risks of Climate Engineering' (2009) 325 *Science* 955.

31 Lianhong Gu *et al*, 'Response of a Deciduous Forest to the Mount Pinatubo Eruption: Enhanced Photosynthesis' (2003) 299 *Science* 2035.

32 Peter Braesicke, Olaf Morgenstern and John Pyle, 'Might Dimming the Sun Change Atmospheric ENSO Teleconnections as We Know Them?' (2011) 12 *Atmospheric Sciences Letters* 184.

33 P Heckendorn *et al*, 'The Impact of Geoengineering Aerosols on Stratospheric Temperature and Ozone' (2009) 4 *Environmental Research Letters* 045108.

34 Jason J Blackstock *et al*, *Climate Engineering Responses to Climate Emergencies* (Novim, 2009).

35 Other relevant international agreements include the Antarctic Treaty System (1959), the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (1967), and the United Nations Convention on the Law of the Sea (1982).

varies among the proposed climate engineering methods. In general, international legal instruments are more applicable to CDR than to SRM.

The leading climate change treaty is the United Nations Framework Convention on Climate Change (UNFCCC), whose objective is the 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.[36] It makes repeated references to the removal of greenhouse gases by sinks, and to the enhancement thereof.[37] Whereas its definition of sink as 'any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere' seems to include CDR, the UNFCCC's Kyoto Protocol—currently the primary platform of national commitments—limits credit for emission reduction via sinks to 'human-induced land-use change and forestry activities'.[38]

Climate engineering proposals to fertilise oceans in order to increase biological carbon dioxide uptake, which have already been the focus of around a dozen field trials,[39] are subject to existing international agreements. Most importantly, fertilisation could be considered ocean dumping. Whether a particular form of ocean dumping is prohibited under the London Convention and its London Protocol, which regulate the practice, depends upon, *inter alia*, the action's purpose, quantity, and potential for harm.[40] Following controversy surrounding ocean fertilisation field trials,[41] the International Maritime Organization (IMO), which administers the Convention and Protocol, resolved that ocean fertilisation does fall within the treaties' scope, and that fertilisation, other than 'legitimate scientific research', should currently not be permitted.[42] It later developed a framework tool for assessing whether a proposed activity is 'legitimate scientific research'.[43]

Due to its broad mandate and the risks to biodiversity from climate change, the Convention on Biological Diversity (CBD) may be relevant to climate engineering. In particular, its parties must work to '[p]revent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species'.[44] This could include

36 United Nations Framework Convention on Climate Change (1992), Art 3.

37 *Ibid,* Arts 3.1, 4 (throughout), 7.2(d), 12.1(a), and 12.1(b).

38 *Ibid*, Art 1.8; Kyoto Protocol to the United Nations Framework Convention on Climate Change (1997), Art 3.3.

39 These field trials are reviewed in Aaron Strong, John J Cullen and Sallie W Chisholm, 'Ocean Fertilization: Science, Policy, and Commerce' (2009) 22 *Oceanography* 236.

40 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972), Art 3.1(b) and Annex 2; its 1996 Protocol, Art 1.4.2 and Annex 1.

41 See eg Aaron Strong *et al*, 'Ocean Fertilization: Time to Move On' (2009) 461 *Nature* 347.

42 Contracting parties to the London Convention and contracting parties to the London Protocol, Resolution LC-LP.1 on the Regulation of Ocean Fertilization (2008).

43 Contracting parties to the London Convention and contracting parties to the London Protocol, Resolution LC-LP.2 on the Assessment Framework for Scientific Research Involving Ocean Fertilization (2010).

44 Convention on Biological Diversity (1992), Art 8(h).

ocean fertilisation, which typically operates by creating algal blooms. Responding to the ocean fertilisation field trials, in 2008 the parties to the CBD took a firmer position than that of the IMO, requesting that

> ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities, including assessing associated risks, and a global, transparent and effective control and regulatory mechanism is in place for these activities; with the exception of small scale scientific research studies within coastal waters.[45]

This apparent divergence between the IMO and the CBD continued in 2010. Just after the former released its framework assessment for legitimate ocean fertilisation research, the parties to the CBD broadened their call, inviting

> [p]arties and other Governments … to consider [e]nsur[ing] … in the absence of science based, global, transparent and effective control and regulatory mechanisms for geo-engineering, and in accordance with the precautionary approach and Article 14 of the Convention, that no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the Convention, and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment.[46]

In a footnote, the statement defined that

> any technologies that deliberately reduce solar insolation or increase carbon sequestration from the atmosphere on a large scale that may affect biodiversity (excluding carbon capture and storage from fossil fuels when it captures carbon dioxide before it is released into the atmosphere) should be considered as forms of geo-engineering which are relevant to the Convention on Biological Diversity.[47]

Compared to CDR, SRM is poorly addressed by international legal instruments. For example, the Environmental Modification Convention prohibits the military use of 'the deliberate manipulation of natural processes—the dynamics, composition or structure of

45 Decisions Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Ninth Meeting (2008), IX/16(C)4.

46 Report of the Tenth Meeting of the Conference of the Parties to the Convention on Biological Diversity (2010), X/33(w).

47 *Ibid*, fn 3. At the time of writing, the CBD Secretariat is forming a liaison group to work on 'defining climate-related geo-engineering, and assessing the potential impacts of geo-engineering on biodiversity'. Secretariat of the Convention on Biological Diversity, 'Call for Experts on Climate-Related Geo-Engineering as it Relates to the Convention on Biological Diversity' (2011), Ref SCBD/STTM/JW/ac/74873.

the Earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space'. However, it explicitly permits peaceful activities.[48]

The most widely discussed SRM proposal, stratospheric aerosol injection, could potentially be interpreted as air pollution, albeit intentional. The Convention on Long-Range Transboundary Air Pollution is of limited applicability, as it is weak, focuses on only Europe's air quality, and addresses pollution 'which has adverse effects … at such a distance that it is not generally possible to distinguish the contribution of individual emission sources or groups of sources'.[49] Sulfate is presently the most likely candidate for aerosol injection, and the Convention's sulfur Protocols, while requiring parties to reduce sulfur emissions, do not prohibit intentional releases.[50] Furthermore, the amount of sulfate to be injected under stratospheric aerosol injection would be small relative to that from 'unintentional' pollution.[51] Customary international law, under which states generally have duties to minimise transboundary harm and to cooperate in mitigating risks, would likely be more relevant.[52]

Finally, stratospheric sulfate aerosol injection could damage the ozone layer, which is already thinned.[53] A thinner ozone layer would allow more ultraviolet radiation to reach the earth's surface, creating risks to the environment and human health. The Montreal Protocol is currently phasing out certain substances which contribute to this depletion.[54] Although the Protocol uses a 'black list' of prohibitions which does not include sulfates, deployment of or research into stratospheric sulfate aerosol injection could instigate action.

III. REGULATORY CHALLENGES

Although some existing international legal instruments may be applicable to climate engineering, as outlined in the previous section, significant regulatory gaps clearly remain. This section describes how the technical, environmental and political characteristics of

48 Convention on the Prohibition of Military or any other Hostile Use of Environmental Modification Techniques (1977), Arts II and III.

49 Convention on Long-Range Transboundary Air Pollution (1979), Art 1(b).

50 Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent (1985); Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on Further Reduction of Sulphur Emissions (1994).

51 The amount necessary is in the order of 5 million metric tons (teragrams) per year. See eg Crutzen (n 20). Current global anthropogenic sulfur emissions are approximately 58 metric tons per year. SJ Smith *et al*, 'Anthropogenic Sulfur Dioxide Emissions: 1850–2005' (2011) 11 *Atmospheric Chemistry and Physics* 1101.

52 See 'Trail Smelter Case. United States of America, Canada. April 16, 1938, and March 11, 1941' 3 *RIAA* 1905; Rio Declaration on Environment and Development (1992), principles 2, 8, 19; International Court of Justice, *Case Concerning the Gabčíkovo-Nagymaros Project* [1997] ICJ Rep 7; International Law Commission, 'Prevention of Transboundary Harm from Hazardous Activities' (2001) A/56 *Official Records of the General Assembly*.

53 Heckendorn *et al* (n 33).

54 Montreal Protocol on Substances that Deplete the Ozone Layer (1987).

climate engineering contribute to regulatory challenges and thus make filling these gaps difficult.

The UK Royal Society's report concluded that '[t]he greatest challenges to the successful deployment of geoengineering may be the social, ethical, legal and political issues associated with governance, rather than scientific and technical issues'.[55] Fortunately, however, presently there are opportunities to identify the challenges, to examine existing law, and to propose and implement new regulatory instruments before risks are borne and any technologies may become locked-in. In short, this is the technology control dilemma: Early on, the risks and negative consequences of a new, powerful technology are poorly known while appropriate regulation is relatively easy to implement. As the risks become clearer, regulation becomes more difficult to enact.[56]

The regulatory challenges vary among the proposed climate engineering methods, and are greater for—and often exclusive to—SRM compared to CDR.[57] In fact, the Royal Society asserted that 'CDR technologies could mostly be adequately controlled by existing national and international institutions and legislation'.[58] Steve Rayner described this as the 'geoengineering paradox':

> The technology that seems to be nearest to maturity and could technically be used to shave a few degrees off a future peak in anthropogenic temperature rise [ie SRM by stratospheric aerosol injection] is likely to be the most difficult to implement from a social and political standpoint, while the technology that might be easiest to implement from a social perspective and has the potential to deliver a durable solution to the problem of atmospheric carbon concentrations [ie ambient air capture CDR] is the most distant from being technically realized.[59]

Some CDR methods which are labelled 'climate engineering' differ little from the enhancement of natural sinks, except in their proposed scale.[60] As with sink enhancement,

55 Royal Society (n 21) xi.

56 'By the time undesirable consequences are discovered, however, the technology is often so much part of the whole economics and social fabric that its control is extremely difficult. This is the dilemma of control. When change is easy, the need for it cannot be foreseen; when the need for change is apparent, change has become expensive, difficult and time consuming.' David Collingridge, *The Social Control of Technology* (St Martin, 1980) 11.

57 In its report, the House of Commons Science and Technology Committee concluded (n 21, 17): 'In our view, geoengineering as currently defined covers such a range of Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM) technologies and techniques that any regulatory framework for geoengineering cannot be uniform.'

58 Memorandum Submitted by the Royal Society to the UK House of Commons Science and Technology Committee (2009), para 13.

59 Steve Rayner, 'The Geoengineering Paradox' (2010) 1 *The Geoengineering Quarterly* 7, www.oxfordgeoengineering.org/pdfs/geoengineering_quarterly_first_edition.pdf (accessed 7 June 2011).

60 Consider, for example, harvesting biomass and sequestering it as soil organic material, or large scale afforestation or reforestation. Johannes Lehmann, John Gaunt and Marco Rondon, 'Bio-Char Sequestration in Terrestrial Ecosystems: A Review' (2006) 11 *Mitigation and Adaptation Strategies for Global Change* 395; Committee on Science, Engineering and Public Policy (n 17).

these methods will require determinations as to whether they qualify as carbon credits, a process which can be managed using existing legal instruments and institutions. In some cases of CDR, local law can adequately deal with environmental concerns, such as how to store captured carbon dioxide. An exception is enhanced maritime storage, particularly through ocean fertilisation, which is associated with greater environmental risks which are transboundary in character. However, even ocean fertilisation is being addressed through the London Convention and Protocol,[61] even though it may not be an effective CDR method.[62]

Furthermore, those difficulties that *are* held in common by both SRM and CDR may not be of the sort to be addressed through regulation. For example, one common concern is that climate engineering is not merely a distraction from addressing the causes of climate change, but presents a 'moral hazard' which will weaken incentives for emissions cuts and adaptation.[63] Although almost all climate engineering researchers and advocates repeatedly emphasise the primacy of emissions cuts,[64] a handful assert that climate engineering could be a substitute.[65] There is also the related possibility that climate engineering research is a slippery slope to deployment,[66] especially considering the

61 Contracting parties to the London Convention and contracting parties to the London Protocol (n 42 and n 43).

62 A report of the Intergovernmental Oceanographic Commission concluded that 'even using the highest estimates for both carbon export ratios and atmospheric uptake efficiencies, the overall potential for ocean fertilization to remove CO_2 from the atmosphere is relatively small'. Doug WR Wallace *et al*, *Ocean Fertilization: A Scientific Summary for Policy Makers* (IOC/BRO/2010/2, 2010). See also Strong *et al* (n 41); Mary W Silver *et al*, 'Toxic Diatoms and Domoic Acid in Natural and Iron Enriched Waters of the Oceanic Pacific' (2010) 107 *Proceedings of the National Academy of Sciences* 20762.

63 See eg Stephen H Schneider, 'Earth Systems Engineering and Management' (2001) 409 *Nature* 417; Mark Lawrence, 'The Geoengineering Dilemma: To Speak or Not to Speak' (2006) 77 *Climatic Change* 245. Ironically, some supporters of climate engineering research are concerned about the moral hazard (David W Keith, 'Geoengineering the Climate: History and Prospect' (2000) 25 *Annual Review of Energy and the Environment* 245), while some skeptics are less so (Martin Bunzl, 'Researching Geoengineering: Should Not or Could Not?' (2009) 4 *Environmental Research Letters* 045104).

64 See eg the first 'headline message' and 'key recommendation' of the Royal Society (n 21, ix): 'The safest and most predictable method of moderating climate change is to take early and effective action to reduce emissions of greenhouse gases. No geoengineering method can provide an easy or readily acceptable alternative solution to the problem of climate change … Parties to the UNFCCC should make increased efforts towards mitigating and adapting to climate change, and in particular to agreeing to global emissions reductions.' For specifics see TML Wigley, 'A Combined Mitigation/Geoengineering Approach to Climate Stabilization' (2008) 314 *Science* 452.

65 Edward Teller, Roderick Hyde and Lowell Wood, 'Active Climate Stabilization: Practical Physics-Based Approaches to Prevention of Climate Change', paper delivered at the National Academy of Engineering Symposium, Washington, DC, 23–24 April 2002; Alan Carlin, 'Global Climate Change Control: Is there a Better Strategy than Reducing Greenhouse Gas Emissions?' (2007) 155 *University of Pennsylvania Law Review* 1401; Barrett (n 11).

66 Climate engineering researcher Ken Caldeira concedes that '[t]here's a slippery slope from laboratory research to large-scale deployment'. Ken Caldeira, 'Has the Time Come for Geoengineering?' (2008) *Bulletin of the Atomic Scientists*, www.thebulletin.org/web-edition/roundtables/has-the-time-come-geoengineering (accessed 7 June 2011).

potential entrenchment of powerful interests under a large research program.[67] Finally, some observers have questioned the ethics of intentionally modifying the earth on a massive scale.[68]

Because, in general, CDR appears to be able to be adequately controlled through existing instruments, this essay will henceforth focus on SRM.

The scientific characteristics of climate change and the technical characteristics of SRM exacerbate the technology control dilemma. Climate science is 'post-normal' science, in which 'facts are uncertain, values in dispute, stakes high and decisions urgent'.[69] Furthermore, SRM presents an extreme case of a risk-risk tradeoff,[70] which makes attempts to apply the precautionary principle ambiguous.[71] It operates in a state of not mere uncertainty, but of ignorance, the condition in which knowledge about both outcomes and their probabilities is low.[72] Finally, climate engineering techniques may be developed and modified rapidly, making a 'connection' between the regulation and technology difficult to maintain.[73]

The development of regulation is a political process, yet the mere discussion of climate engineering gives rise to a complicated political landscape. Among environmental advocates, climate engineering (to the extent that it is even discussed) has divided pragmatists, who focus on minimising the impacts of climate change, and 'deeper' Greens, who seek a more modest relationship with the planet.[74] Public statements from environ-

67 David G Victor *et al*, 'The Geoengineering Option: A Last Resort against Global Warming?' (2009) 88 *Foreign Affairs* 64, 72.

68 See eg Dale Jamieson, 'Ethics and Intentional Climate Change' (1996) 33 *Climatic Change* 323.

69 Silvio O Funtowicz and Jerome R Ravetz, 'Science for the Post-Normal Age' (1993) 25 *Futures* 739. See also Mike Hulme, *Why We Disagree about Climate Change: Understanding Controversy, Inaction and Opportunity* (Cambridge University Press, 2009) 78–81.

70 John D Graham and Jonathan Baert Wiener (eds), *Risk vs Risk: Tradeoffs in Protecting Health and the Environment* (Harvard University Press, 1995).

71 In the UNFCCC, the Precautionary Principle is given as: 'Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures.' UNFCCC (n 36) Art 3.3. However, both climate change and climate engineering pose 'threats of serious or irreversible damage' and lack 'full scientific certainty'. Consequently, the relationship between climate engineering and precaution is unclear.

72 Andy Stirling distinguishes risk, uncertainty, ambiguity and ignorance. Andy Stirling, 'Risk, Uncertainty and Precaution: Some Instrumental Implications from the Social Sciences' in Frans Berkhout, Melissa Leach and Ian Scoones (eds), *Negotiating Environmental Change: New Perspectives from Social Science* (Edward Elgar, 2003).

73 Roger Brownsword, *Rights, Regulation, and the Technological Revolution* (Oxford University Press, 2008).

74 Amongst the groups sympathetic to climate engineering research, the Environmental Defense Fund is a convening partner of the Solar Radiation Management Governance Initiative, and Greenpeace and WWF UK are stakeholder partners thereof. 'Solar Radiation Management Governance Initiative', www.srmgi.org (accessed 7 June 2011). Friends of the Earth (UK) has supported ambient air CDR but opposed other CDR methods with wider environmental side-effects and SRM by aerosol injection. Friends of the Earth (UK), *Briefing Note: Geoengineering* (2009). Nature Conservancy's lead scientist called for an aggressive climate engineering research program, albeit with some caveats. M Sanjayan, 'Forum: Geoengineering Research' (2011) 27 *Issues in Science and Technology*, www.issues.org/27.2/forum.html (accessed 7 June 2011). The

mental groups have often criticised climate engineering but have fallen short of outright condemnation of it or calls for its prohibition.[75] At the other end of the traditional political spectrum, industrial interests that would benefit from continued greenhouse gas emissions have been notably quiet on climate engineering.[76] Some of these have previously denied the threat of anthropogenic climate change;[77] backing climate engineering could be interpreted as a tacit admission. Moreover, public support of climate engineering from such industries may make it even more controversial. Among the public, the prospect of scientists tinkering with the entire planet's climate systems is likely to be greeted with concern and skepticism.[78] Given this complex political landscape, establishing legitimacy will be both crucial and difficult for any regulatory scheme.

The regulatory challenges raised by the political characteristics of SRM are most apparent in the deployment context. Various countries and powerful interests would disagree about what climate is ideal, and the possibility of unilateral deployment would make any agreements difficult to maintain. Furthermore, the low estimated financial cost of SRM would enable small nations and non-state actors to implement it. How would the international community manage SRM deployment, some of which could be unauthorised and performed by rogue actors? Furthermore, some parties may feel that they have been harmed by the negative effects of SRM. In these cases, climate counter-engineering and militarisation appear possible. Finally, SRM would need to be maintained

Natural Resources Defense Council sent its Director of Climate Programs to the 2010 Asilomar meeting (see text to nn 102–6), and it later issued a report backing research into biochar for CDR. Michael MacCracken *et al*, *The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques* (Climate Institute, 2010) 32; Stephen Brick, *Biochar: Assessing the Promise and Risks to Guide US Policy* (Natural Resources Defense Council, 2010). For groups opposed to climate engineering, see two efforts led by the ETC Group: *Open Letter to the Climate Response Fund and the Scientific Organizing Committee* (ETC Group, 2010); Hands Off Mother Earth, 'Organisations', www.handsoffmotherearth.org/organisations (accessed 7 June 2011).

75 See eg David Adam, 'Extreme and Risky Action the Only Way to Tackle Global Warming, Say Scientists' *The Guardian*, 1 September 2008; Doug Parr, 'Geo-Engineering is No Solution to Climate Change' *The Guardian*, 1 September 2009.

76 Industrial and corporate support for climate engineering research has been limited. The American Enterprise Institute, a business-friendly conservative think tank, has a geoengineering policy program. American Enterprise Institute for Public Policy Research, 'Research Areas: Geoengineering', www.aei.org/yra/100009 (accessed 7 June 2011). The CDR project Cquestrate was funded by the oil company Shell. Cquestrate, 'About Us', www.cquestrate.com/about-us (accessed 7 June 2011).

77 'For more than a decade the Global Climate Coalition, a group representing industries with profits tied to fossil fuels, led an aggressive lobbying and public relations campaign against the idea that emissions of heat-trapping gases could lead to global warming … But … even as the coalition worked to sway opinion, its own scientific and technical experts were advising that the science backing the role of greenhouse gases in global warming could not be refuted.' Andrew C Revkin, 'Industry Ignored its Scientists on Climate' *New York Times*, 23 April 2009. See also David Adam, 'Royal Society Tells Exxon: Stop Funding Climate Change Denial' *The Guardian*, 20 September 2006.

78 The only significant investigation into public opinion on climate engineering is the NERC Public Dialogue on Geoengineering Steering Group (n 22).

for a long time—perhaps centuries—because its cessation would result in a dangerously rapid temperature increase.[79] Establishing institutions for such a time scale is obviously challenging, and any parties responsible for SRM maintenance would wield enormous power.

Some challenges to effectively limit the environmental and human health effects of SRM extend from deployment scenarios to field research. This is particularly the case because weather is naturally variable, and thus field trials may need to increase quickly in size in order to produce significant results discernable from background noise. Furthermore, in the case of stratospheric aerosol injection, merely observing whether the particles stay aloft or sink would require large aerosol clouds. Some scientists have gone so far as to assert that 'geoengineering cannot be tested without full-scale implementation'.[80] Because current SRM models predict spatially uneven results and negative side-effects, both deployment and field trials could place the environment and people at significant risk. This will challenge existing international norms of transboundary risk, and raise questions of liability. Furthermore, SRM deployment and large field trials may have entirely unpredicted effects.[81] Populations near test areas will be in a situation similar to that of human biomedical research subjects, yet it is unclear how to apply traditional bioethical principles such as respect for autonomy, beneficence and justice.[82] These risks, both known and unknown, are most apparent in the case of stratospheric aerosol injection, which by its nature will impact a large area. However, smaller scale and more remote methods, such as spraying seawater to increase the brightness of clouds and injecting microbubbles into the ocean, also pose environmental risks.[83]

Nevertheless, effective regulation of SRM field research is needed soon. SRM research is crucial in order to improve understanding of possible responses to climate change and to prevent uninformed action in the face of abrupt climate change. Furthermore, scientists are moving rapidly toward SRM field experiments. Calls for coordinated funding of

79 SRM 'may have to last for the length of perhaps a millennium. And … the efforts will be of little use unless we continue the aerosol emission without interruptions.' Lennart Bengtsson, 'Geo-Engineering to Confine Climate Change: Is it at all Feasible?' (2006) 77 *Climatic Change* 229, 232. See also H Damon Matthews and Ken Caldeira, 'Transient Climate-Carbon Simulations of Planetary Geoengineering' (2007) 104 *Proceedings of the National Academy of Sciences* 9949.

80 Alan Robock *et al*, 'A Test for Geoengineering?' (2010) 327 *Science* 530, 530.

81 Alan Robock, '20 Reasons why Geoengineering may be a Bad Idea' (2008) 64 *Bulletin of the Atomic Scientists* 14.

82 '[T]he potential severity of its effects merits the application of ethical norms similar to those governing biomedical studies. We suggest that [SRM] research is, in this respect, similar to nuclear weapons testing, in which an experiment's indirect effects are dangerous enough to be ethically significant.' David R Morrow, Robert E Kopp and Michael Oppenheimer, 'Toward Ethical Norms and Institutions for Climate Engineering Research' (2009) 4 *Environmental Research Letters* 045106, 3. See also Pablo Suarez, Jason J Blackstock and Maarten van Aalst, 'Towards a People-Centered Framework for Geoengineering Governance: A Humanitarian Perspective' (2010) 1 *The Geoengineering Quarterly* 2.

83 See eg Alan Robock, 'Bubble, Bubble, Toil and Trouble' (2011) 105 *Climatic Change* 383.

climate engineering research are almost ubiquitous in reports and articles.[84] Some scientists are outlining how a research program could scale up to large outdoor trials.[85] A new project in the UK plans to test aerosol spraying outdoors.[86] A private American company intends to undertake a 10,000km^2 trial of maritime cloud brightening.[87] One Russian team, led by a prominent scientist, has already conducted a small scale field experiment, spraying aerosols into the lower atmosphere.[88]

Climate engineering scientists and advocates themselves acknowledge the need for regulation of SRM research. For example, the Royal Society report concluded:

> A research governance framework is required to guide the sustainable and responsible development of research activity so as to ensure that the technology can be applied if it becomes necessary. Codes of practice for the scientific community should be developed, and a process for designing and implementing a formal governance framework initiated.[89]

Because discussions of SRM deployment quickly raise problematic matters, such as geopolitics, jointly considering the regulation of field research and that of deployment will unnecessarily impede the progress of the former. Efforts toward SRM regulation will thus be more likely to be successful if they are initially limited to matters of field research.

IV. THE REGULATION OF SCIENTIFIC RESEARCH

The previous section demonstrated that effective regulation of climate engineering will be difficult; that the regulatory challenges vary between CDR and SRM, and between deployment and research; and that regulation of SRM field research should be developed

84 The Royal Society (n 21) called for £10 million (US $16 million) per year. David W Keith *et al* wrote: 'An international research budget growing from about $10 million to $1 billion annually over this decade would probably be sufficient to build the capability to deploy SRM and greatly improve the understanding of its risks.' David W Keith, Edward Parson and M Granger Morgan, 'Research on Global Sun Block Needed Now' (2010) 463 *Nature* 426, 427. The lead scientist of the Nature Conservancy called for US $50 million per year. Sanjayan (n 74).

85 See eg Ken Caldeira and David W Keith, 'The Need for Climate Engineering Research' (2010) 27 *Issues in Science and Technology*, www.issues.org/27.1/caldeira.html (accessed 7 June 2011).

86 The Stratospheric Particle Injection for Climate Engineering project 'will investigate the effectiveness of stratospheric particle injection. It will address the three grand challenges in solar radiation management: 1. How much, of what, needs to be injected where into the atmosphere to effectively and safely manage the climate system? 2. How do we deliver it there? 3. What are the likely impacts?' 'Details of Grant Ep/I01473x/1' (n 22).

87 Ben Webster, 'Bill Gates Pays for "Artificial" Clouds to Beat Greenhouse Gases' *The Times*, 8 May 2010.

88 Y Izrael *et al*, 'Field Studies of a Geo-Engineering Method of Maintaining a Modern Climate with Aerosol Particles' (2009) 34 *Russian Meteorology and Hydrology* 635. The lead author was chairman of the Soviet Committee for Hydrometeorology, was vice-chair of the IPCC, and is director of the Institute of Global Climate and Ecology of the Russian Academy of Sciences.

89 Royal Society (n 21) xii.

first and separately. Before going into further detail, an exploration of the logic and legal basis of regulation of scientific research is warranted.

Any current or proposed regulation of scientific research must address a potential challenge that such research or the communication of its results is protected by fundamental rights, particularly the right to free speech. In general, the case for such protection is weak. For example, while the UN Universal Declaration on Human Rights recognises a right 'to share in scientific advancement and its benefits', it does not refer to the actual conducting of scientific research.[90] Although the Charter of Fundamental Rights of the European Union clearly states that 'The arts and scientific research shall be free of constraint', this right must be balanced against others. However, the right is yet to be interpreted by the courts due to the newness of the document.[91] In contrast, several international agreements do acknowledge or even regulate certain dangerous or unethical scientific practices.[92] Nationally, claims to US First Amendment protection of research are generally limited to the content of science, not its practice. For example, a seminal paper which asserts a general constitutional right to research concedes that:

> the right to experiment—the right to select appropriate means of conducting research—is a weaker right than the right to select the end of research. The right to experiment is less absolute: it includes the qualification that although the scientist is free to choose any means of conducting research he thinks scientifically sound, he may not cause direct, substantial harm to the cognizable interests of others.[93]

However, even these claims may not withstand scrutiny.[94]

There are three sets of reasons to regulate or prohibit certain forms of scientific research. Each has relationships with regulation, rights, and climate engineering.

First, some concerns about scientific research are based upon the possible implications or misuse of results. Perhaps the best-known instance is the so-called 'dual-use' technologies, which have both peaceful and military or terroristic uses. Scrutiny of fields

90 United Nations Universal Declaration on Human Rights (1948), Art 27.

91 Charter of Fundamental Rights of the European Union (2000), Art 13. The Charter became effective in 2009. Among the Charter's other passages which could be relevant in the context of scientific research are human dignity (Art 1), respect for privacy (Art 7), and protection of personal data (Art 8).

92 See eg Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction (1972); Declaration of Helsinki (1975, revised through 2000); UNESCO Universal Declaration on the Human Genome and Human Rights (1997).

93 John A Robertson, 'The Scientist's Rights to Research: A Constitutional Analysis' (1977) 51 *Southern California Law Review* 1203, 1206. See also R Alta Charo, 'Prepared Statement of R Alta Charo' in *Cloning: A Risk to Women? Hearing before the Subcommittee on Science, Technology and Space of the Committee on Commerce, Science and Transportation, United States Senate* (US Government Printing Office, 2002) 29, which similarly asserts a right to research and concedes that 'even protected activities are subject to reasonable regulation to avoid interfering with the rights of others'.

94 J Weinstein, 'Democracy, Individual Rights and the Regulation of Science' (2009) 15 *Science and Engineering Ethics* 407.

such as biological and nuclear sciences has increased, in some cases resulting in new laws.[95] Similarly, certain topics, such as the relationships among race, genes and intelligence, may have troubling social implications and are often taboo for researchers.[96] A third example is potential breaches of privacy when communicating research results. In this set of reasons for concern, if experiments were to occur but the results never released, there would be no cause for unease. Thus, concern is not with the experiment *per se* but with the communication of its results. Therefore, relative to the other two categories presented here, the regulation of the publication of results from research which is otherwise permitted would face the strongest criticism that it would violate free speech rights. For climate engineering, the dual-use concerns could possibly be relevant, given the low economic cost of SRM and its potential for militarisation. Perhaps more likely, however, opponents of climate engineering could raise the spectre of the slippery slope, described above, and argue that dissemination of the results of climate engineering research would make its deployment unacceptably more probable.

Second, certain actions in the research process, such as the destruction of human embryos or animal testing, may be seen as inherently immoral. To its strongest critics, whether the action occurs within or outside of the research context matters little, if at all: If destroying a human embryo is wrong in the lab, then it is also wrong elsewhere. However, the law does, in fact, often distinguish based upon the scientific context. For example, research practices which may be permitted in the lab would be animal cruelty outside, due to the potential benefits of research. The challenge to developing regulation of these research actions will be primarily political, in that opponents of an action viewed as inherently immoral may be unlikely to compromise. To them, a law designed to minimise but not prohibit the practice may be seen as a tacit endorsement. It is unlikely that climate engineering research would be the subject of regulation or prohibition based upon the inherent immorality of the action. Even those who argue that climate engineering deployment may be fundamentally wrong concede that its research may need to go forward.[97]

95 See eg Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism Act 2001 (USA), s 81; Public Health Security and Bioterrorism Preparedness and Response Act 2002 (USA); Committee on Advances in Technology and the Prevention of their Application to Next Generation Biowarfare Threats, *Globalization, Biosecurity, and the Future of the Life Sciences* (National Academies Press, 2006).

96 See eg Steven Rose, 'Darwin 200: Should Scientists Study Race and IQ? No: Science and Society Do Not Benefit' (2009) 457 *Nature* 786; Stephen Ceci and Wendy M Williams, 'Darwin 200: Should Scientists Study Race and IQ? Yes: The Scientific Truth Must be Pursued' (2009) 457 *Nature* 788.

97 Both Dale Jamieson and Stephen M Gardiner place the ethical bar for climate engineering quite high, but concede that research should go forward. Jamieson (n 68); Stephen M Gardiner, 'Is "Arming the Future" with Geoengineering Really the Lesser Evil? Some Doubts About the Ethics of Intentionally Manipulating the Climate System' in Stephen M Gardiner *et al* (eds), *Climate Ethics: Essential Readings* (Oxford University Press, 2010). See also Claire L Parkinson, *Coming Climate Crisis? Consider the Past, Beware the Big Fix* (Rowman & Littlefield, 2010).

Finally, scientific research may negatively affect human health or the environment. Of course, some people give their informed consent to be affected, sometimes negatively, by an experiment. The oversight of human subjects research is perhaps the most established form of regulation of scientific conduct. More relevant to climate engineering research are externalities which pose risks to non-consenting third parties and the environment. As with the previous category, there is a strong legal case to be made that the scientific context is relevant, and that the positive external benefit of greater knowledge may outweigh the negative external risks to non-consenting people and the environment. This is not *carte blanche* for unregulated scientific conduct. The balance of these benefits and risks is the fundamental question of the regulation of climate engineering research.

Perhaps the best historical analogy to SRM is above-ground nuclear weapons testing. It carried significant risks to the health of humans, who essentially were non-consenting research subjects, and to the environment, including major irreversible harm. The tests operated under similar conditions of ignorance and post-normal science. Furthermore, as in the case of climate engineering, these risks needed to be balanced with others, such as that of a nuclear attack by one's opponents, and the benefits of reducing the risks.[98] However, above-ground nuclear weapons testing largely ended before the implementation of modern norms of human research subjects and environmental protection.[99] Thus, it is unclear how and whether such testing could be compatible with current bioethical standards.

V. TOWARD THE REGULATION OF SRM FIELD RESEARCH

In this section, I will highlight the background, specific strengths and challenges of a current effort to regulate SRM field research, namely the SRM Governance Initiative, emphasising claims to legitimacy and the definition of research.

Any regulatory regime for SRM field research must address the challenges described above in section III: It must minimise the risks to human health and the environment posed by experiments, and ensure that trials are as encapsulated and reversible as possible. To maintain ethical norms, it must obtain some form of consent from those who are placed at risk, while providing recourse for those who are demonstrably and significantly impacted. It must prevent commercial interests from unduly influencing the research in a manner contrary to the public interest. It must be flexible enough to adapt to a variety

98 Of course, given the dynamics of escalation and mutually assured destruction during the Cold War, the risk of attack may have been exaggerated, and the need for testing a self-fulfilling prophecy.

99 The Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water took effect in 1963. France and China continued limited atmospheric nuclear testing through 1974 and 1980, respectively. Major milestones in human research subject protection include the Nuremberg Code (1947), the Declaration of Helsinki (1964), and the Belmont Report (1979).

of SRM proposals, a wide range of scales, and an evolving knowledge base. And it must perform these functions under conditions of ignorance, political volatility, and post-normal science.

Unsurprisingly, the present actors in the policymaking arena differ over how to proceed toward regulation of SRM research. How wide a consensus is needed? Climate engineering research is occurring in only a few countries. Is agreement needed throughout the international community, or only among the capable countries? How should top-down and bottom-up approaches to developing regulation be balanced? Is a 'stamp of approval' from national governments or international bodies needed, or can the scientific community act on its own? How binding must regulation be? Are mere 'guidelines' acceptable?

Some observers believe that binding regulations are not only unnecessary, but could do more harm than good. They emphasise the present lack of knowledge and the absence of incentives for countries with the capacity for climate engineering to endorse a binding agreement. Furthermore, detailed constraints on behaviour now may prevent valuable research from occurring. Instead, such writers thus recommend the development of norms from the bottom up.[100]

The Convention on Biological Diversity, as described above, may offer a vehicle for the regulation of climate engineering research.[101] Almost all countries are parties to it, and decisions of its Conference of Parties thus carry significant weight. However, the United States—the world's largest economy and leading site of research—is not a party. Furthermore, the CBD more closely resembles a framework treaty, and detailed obligations have thus far required further protocols.

Climate engineering scientists and advocates have already taken steps toward regulation of climate engineering research. In March 2010, they organised a week-long meeting at the Asilomar Conference Grounds in California in order to develop self-regulation, explicitly invoking early self-regulation by the first genetic engineering researchers,[102] which has been touted as a paragon of scientific responsibility.[103] However,

100 David G Victor, 'On the Regulation of Geoengineering' (2008) 24 *Oxford Review of Economic Policy* 322; Keith *et al* (n 84). A scenario study by the RAND Corporation concludes that the US leadership should prefer norms to regulate SRM research if it believes that SRM could be effective. Robert J Lempert and Don Prosnitz, *Governing Geoengineering Research: A Political and Technical Vulnerability Analysis of Potential Near-Term Options* (RAND Corporation, 2011).

101 See text to nn 44–47.

102 The Asilomar International Conference on Climate Intervention Technologies chose the same venue as the 1975 Asilomar Conference on Recombinant DNA, and was even informally dubbed 'Asilomar 2'. The 'honorary chair' of its Scientific Organizing Committee was Paul Berg, who was the chair and a principle architect of the 1975 conference. 'The conference recalled the important role that early agreement on guidelines by the recombinant DNA research community played in limiting the research risk and clearing a path for that research.' MacCracken *et al* (n 74) 4.

103 Retrospective analyses of the 1975 meeting are more mixed. See eg Marcia Barinaga, 'Asilomar Revisited: Lessons for Today?' (2000) 287 *Science* 1584.

the meeting met with strong criticism, from both inside and outside the climate engineering community, arising from a lack of transparency, concerns over personal commercial interests, and the limitations of self-regulation.[104] Consequently, the conference's legitimacy suffered, and it produced only a modest statement.[105] The conference leadership later produced five principles for climate change research:

1. Collective benefit …
2. Establishing responsibility and liability …
3. Open and cooperative research …
4. Iterative evaluation and assessment …
5. Public involvement and consent …[106]

More recently, the UK's Royal Society, in partnership with a major US environmental organisation and the developing world's network of academies of science, launched the SRM Governance Initiative, which 'seeks to develop guidelines to ensure that geoengineering research is conducted in a manner that is transparent, responsible and environmentally sound'.[107] In contrast to the Asilomar meeting, it focuses on the regulation of SRM research, excluding CDR.

As the Asilomar process highlighted, the development of legitimacy presents a particularly difficult task in order for any regulation of SRM field research to be effective. Climate engineering carries such enormous risk and is so controversial that any regulatory regime must pass a high bar of legitimacy. State lawmakers, often a source of regulation with great legitimacy, have generally been quiet on the topic, potentially due to its political volatility.[108] However, legislation is not the sole claim to legitimacy. Robert Baldwin cites other means: accountability, due process, expertise, and efficiency.[109]

104 See eg Joe Romm, 'Exclusive: Chief Sponsor of Landmark Climate Manipulation Conference Maintains Close Financial Ties to Controversial Geo-Engineering Company', *Climate Progress*, 18 March 2010, http://climateprogress.org (accessed 7 June 2011); ETC Group (n 74).

105 The statement implicitly acknowledges the limitations of complete self-regulation: 'The group recognized that given our limited understanding of these methods and the potential for significant impacts on people and ecosystems, further discussions must involve government and civil society.' Michael MacCracken *et al*, *Asilomar Conference Statement* (2010), reprinted as Appendix B in MacCracken *et al* (n 74).

106 Margaret Leinen, 'The Asilomar International Conference on Climate Intervention Technologies: Background and Overview' (2011) 4 *Stanford Journal of Law, Science & Policy* 1.

107 'Solar Radiation Management Governance Initiative' (n 74).

108 Consider the case of John Holdren, who as US President Obama's newly appointed top science advisor came under strong criticism after saying that climate engineering must 'be looked at. We don't have the luxury of taking any approach off the table', and that 'we might get desperate enough to want to use it'. Seth Borenstein, 'Obama Looks at Climate Engineering' *Associated Press*, 8 April 2009. Holdren later clarified his position. An exception to the trend of politicians avoiding discussion of climate engineering is UK House of Commons Science and Technology Committee (n 21).

109 Robert Baldwin, *Rules and Government* (Clarendon, 1995).

The SRM Governance Initiative may establish its legitimacy claim by emphasising expertise. Whereas the Asilomar meeting was a one-off event involving many individuals, almost entirely from industrialised countries, gathered under the banner of a largely unknown organisation,[110] the new project's convening partners are the world's oldest scientific academy (the Royal Society), the union of scientific academies of the developing world (TWAS), and a major environmental organisation (Environmental Defense Fund). Its working group further reinforces this expertise and diversity with, for example, representatives of other environmental organisations, and one-third of its members are from the developing world. On top of that, the working group contains prominent skeptics of climate engineering.[111]

Another critical yet difficult requirement will be a definition of 'field research'. At the lower boundary, as laboratory and small field experiments increase in scale, at what point should they be regulated? The UK Science and Technology Committee proposed that small SRM field tests need comply only with a set of international principles (yet to be agreed upon), as long as the project has a 'negligible or predictable environmental impact' and 'no trans-boundary effects'. However, if assessment of potential impacts on the environment and human health is among the purposes of a novel experiment, how can negative effects be ruled out *ex ante*? A more precautionary approach may be justified, given the potential negative consequences and the condition of risk ignorance. The initial placement of the lower regulatory threshold at the transition from the laboratory to the field would be advantageous: It would be unambiguous, and it would identify any negative environmental or health effects better and sooner. If early experiments indicate *de minimis* risk, then the lower boundary could be raised.

How to define the upper end of research, distinguishing it from deployment, is less clear. If there is no sharp line between them, and if some scientists argue that relevant field research amounts to small scale deployment, how can regulation be limited to the former?[112] Could any definition prevent deployment from masquerading as research?[113] Analogous cases may be able to shed light on a path forward.

First, the development of drugs and medical devices proceeds through stages of clinical trials before approval.[114] Like SRM field tests, these trials operate in the environ-

110 The Asilomar meeting was convened by the Climate Response Fund, which has seen little activity other than the meeting.

111 Robock (n 81); Clive Hamilton, 'An Evil Atmosphere is Forming around Geoengineering' *New Scientist*, 21 July 2010.

112 Robock *et al* (n 80).

113 Consider that Japanese and Icelandic whalers harvest hundreds of whales per year claiming 'scientific research' despite an international moratorium. International Convention for the Regulation of Whaling (1946), Art VIII; Schedule to the International Convention for the Regulation of Whaling, para 10(e) (adopted 1982); International Whaling Commission, 'Scientific Permit Whaling', http://iwcoffice.org/conservation/permits.htm (accessed 14 June 2011).

114 See generally Richard E Ashcroft and Adrian M Viens, 'Clinical Trials' in Peter A Singer and Adrian M Viens (eds), *Cambridge Textbook of Bioethics* (Cambridge University Press, 2008).

ment (ie, the human body) where they may eventually be utilised, and they carry significant risk. Furthermore, there is some lack of clarity at the upper boundary of research. In later stage clinical trials, research may provide medical benefits. Consequently, the actors have dual roles: Clinical researchers can be cast into the second role of physician, and research subjects seek to participate in experiments expecting therapeutic benefits, and can thus simultaneously be patients.[115] The clinical trials are generally reviewed by an institutionally-affiliated ethics board, while approval of the drug or device is done by national or EU regulators.[116] However, even after approval, post-marketing surveillance can further clarify the safety and effectiveness of the drug or device.[117]

Second, genetically modified organisms are similarly tested in increasingly large trials, moving from the laboratory to the field. In the EU, for example, an extensive regime regulates and distinguishes among field trials, agricultural production, and consumption as food and feed.[118] There is a relatively clear upper boundary for research, in this case 'placing on the market' a GMO product.[119] Regulations address the need for public consultation;[120] labelling, traceability and valid methods of detection;[121] the coexistence of GMO and non-GMO agriculture;[122] and the avoidance of accidental transboundary movement.[123]

Finally, research into ocean fertilisation, as described above, is newly regulated under international law. The IMO has developed a framework to determine whether a project is 'legitimate scientific research', which is based upon four criteria:

115 Nancy MP King and Larry R Churchill, 'Clinical Research and the Physician-Patient Relationship: The Dual Roles of Physician and Researcher' in Singer and Viens, *ibid*; Madison Powers, 'Theories of Justice in the Context of Research' in Jeffrey P Kahn, Anna C Mastroianni and Jeremy Sugarman (eds), *Beyond Consent: Seeking Justice in Research* (Oxford University Press, 1998).

116 Clinical trials are regulated in the EU under the European Clinical Trial Directive (2001/20/EC), and in the US under the so-called 'Common Rule' (45 CFR 46).

117 Post-marketing surveillance is sometimes called 'phase IV clinical trials'.

118 Directive on the Deliberate Release into the Environment of Genetically Modified Organisms (2001/18/EC); Regulation on Genetically Modified Food and Feed (EC, No 1829/2003).

119 '"[P]lacing on the market" means making available to third parties, whether in return for payment or free of charge.' Directive 2001/18/EC (n 118) Art 2(B).

120 Directive 2001/18/EC (n 118) Art 24; Decision Laying Down Detailed Arrangements for the Operation of the Registers for Recording Information on Genetic Modifications in GMOs (2004/204/EC); Regulation (EC) No 1829/2003 (n 118) Art 28.

121 Regulation (EC) No 1829/2003 (n 118); Regulation Concerning the Traceability and Labelling of Genetically Modified Organisms and the Traceability of Food and Feed Products Produced from Genetically Modified Organisms (EC, No 1830/2003); Regulation on Detailed Rules for the Implementation of Regulation (EC) No 1829/2003 (EC, No 641/2004).

122 Commission Recommendation on Guidelines for the Development of National Co-Existence Measures to Avoid the Unintended Presence of GMOs in Conventional and Organic Crops (2010/C200/01).

123 Cartagena Protocol on Biosafety to the Convention on Biological Diversity (2000); Regulation on Transboundary Movements of Genetically Modified Organisms (EC, No 1946/2003).

> The proposed activity should be designed to answer questions that will add to the body of scientific knowledge …
>
> Economic interests should not influence the design, conduct and/or outcomes of the proposed activity …
>
> The proposed activity should be subject to scientific peer review at appropriate stages in the assessment process …
>
> The proponents of the proposed activity should make a commitment to publish the results in peer reviewed scientific publications.[124]

If the proposal is deemed to be legitimate, passes a six-point environmental assessment, and is not otherwise contrary to the London Convention and Protocol, it may conditionally proceed while being monitored. Although ocean fertilisation is a proposed form of CDR, it resembles SRM schemes in its risks of large transboundary environmental effects. Thus, the framework may be able to provide a precedent and model for making the distinction between research and deployment.[125]

However, these cases are of rather limited utility. SRM field research has three characteristics, described above, which make its regulation challenging, yet these characteristics are not shared by these examples. First, effective outdoor research into SRM may require large scale testing, bordering on deployment, whereas the effects and risks of a drug, a GMO crop and ocean fertilisation can generally be assessed from experiments of a limited scale. Second, the potential consequences of experimenting with the earth's atmosphere and climate are greater than those posed by the examples. While the significance of injured research participants, genetic contamination and reduced marine biodiversity should not be belittled, I assert that SRM—even its field research—poses risks of a greater magnitude. Third, in all three cases, 'deployment' (ie, use beyond the test scale) is legally prohibited until research indicates that a particular application poses an acceptable level of risk to human health and the environment. Of course, an international moratorium on SRM deployment could address this gap, and will be needed in any effective regulatory regime for SRM research.[126] However, such a moratorium would need to define the boundary of scale between research and deployment, and thus presents something more like tautology instead of a step toward the regulation of research.

124 Contracting parties to the London Convention and contracting parties to the London Protocol (n 43).

125 David Santillo and Paul Johnston, 'Governance of Geoengineering Research Cannot be Left to Voluntary Codes of Conduct' (2010) 1 *The Geoengineering Quarterly* 4; Till Markus, 'Regulating Scientific Ocean Fertilization Experiments under the Law of the Sea', paper delivered at the Bremen Environmental Law Conference, 'The Law on Climate Engineering', Bremen, 17 February 2011.

126 Depending on interpretations of the role and language of the CBD, such a moratorium may already exist. See text to nn 44–47.

CONCLUSION: IMPLICATIONS FOR THE SRM GOVERNANCE INITIATIVE

Climate engineering is coming under increasing consideration, and may prove to be an important component of a portfolio of responses to the threat of climate change. However, it presents several regulatory challenges. Key to overcoming them is the separation of solar radiation management (SRM) climate engineering from carbon dioxide removal (CDR), and of deployment from research. CDR can generally be controlled through existing legal instruments and institutions. SRM presents a more difficult case, and discussions often become mired in the geopolitics of deployment. Thus, initial steps toward regulation should focus on research. Because this is the approach of the SRM Governance Initiative, it holds potential for significant progress toward regulation of SRM research. Furthermore, the initiative may be able to stake a particular claim to legitimacy via expertise. However, crafting an effective definition of field research will still present a significant challenge. More binding, top-down regulation or less binding, bottom-up norms remain possible alternatives. The outcome will largely be politically contingent.

Climate Engineering Research: A Precautionary Response to Climate Change?

*Jesse L. Reynolds and Floor Fleurke**

In the face of dire forecasts for anthropogenic climate change, climate engineering is increasingly discussed as a possible additional set of responses to reduce climate change's threat. These proposals have been controversial, in part because they – like climate change itself – pose uncertain risks to the environment and human well-being. Under these challenging circumstances of potential catastrophe and risk-risk trade-off, it is initially unclear to what extent precaution is applicable. We examine what precaution is and is not, and make a prima facie case that climate engineering may provide means to reduce climate risks. When precaution is applied to the currently pertinent matter of small to moderate scale climate engineering field tests, we conclude that precaution encourages them, despite their potential risks.

I. Introduction

The likely impacts of anthropogenic climate change on humans and the environment are vast. Mitigating the risks through greenhouse gas emissions abatement requires overcoming an extremely challenging collective action problem. However, efforts thus far to reduce these risks have been disappointing.

As the evidence and probable severity of climate risks have mounted, a wider range of options is now being considered. Efforts toward emissions abatement were the first global response, and then adapting society and ecosystems to new climates became a second legitimate category of action. Now, proposals to develop the means to intentionally intervene on massive scales in global physical, chemical, and biological systems in order to counterbalance climate change are being seriously discussed. While diverse, these proposed *climate engineering* (CE) or *geoengineering* methods are controversial for several reasons, including the contention that they pose uncertain but potentially serious risks to humans and the environment.

In debates over CE, precaution is often invoked. Daniel Bodansky predicted that precaution would "be invoked frequently and loudly at the international level" and possibly contribute to an international prohibition.[1] The Conference of Parties to the Convention on Biological Diversity cited "the precautionary approach" in a nonbinding advisory statement against CE activities that may affect biodiversity.[2] Moreover detractors of CE also often cite precaution as a rationale for opposing CE research and/or deployment.[3] However, in this article, we assert that a precautionary approach favours improving knowledge about CE options through research, including field experiments, but in a manner that recognizes risks.

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1 Daniel Bodansky, "May We Engineer the Climate?", 33 *Climatic Change* (1996), 309, at 312.

2 Decision X/33.8(w), Biodiversity and Climate Change: Report of the Tenth Meeting of the Conference of Parties to the Convention on Biological Diversity, UN Doc. UNEP/CBD/COP/10/27, 20 January 2011.

3 See, e.g., ETC Group, "The ABCs of Ensuring Precaution on Geoengineering", 5 October 2010, available on the Internet at <http://www.etcgroup.org/sites/www.etcgroup.org/files/geoE_ETC4COP11_final4web.pdf> (last accessed on 6 March 2013).

II. Climate Change and Climate Engineering

A brief review of the risks of and potential responses to the threat of climate change will contextualize CE. Greenhouse gas emissions have caused their atmospheric concentrations to rise at an unprecedented rate, and their emission rates continue to grow. Both temperatures and precipitation figures are rising. Because climate change lags relative to emissions, there is an unknown commitment to future climate change. Climate change is accelerating an already disturbing rate of species extinction. In terms of human impacts, analyses are highly sensitive to the assumed discount rate, and their estimated annual costs range from 1% to 20% of global economic activity.[4] Food production and water resources will be disrupted. Infectious diseases, extreme weather events, and involuntary migration will likely increase in frequency and magnitude. Low-lying coastal areas, including entire countries, will be inundated. In almost all of these aspects, poor populations will suffer disproportionately. Meanwhile, the Kyoto Protocol and the latest nonbinding commitments are unlikely to keep global warming below the target of 2°C, and further emissions cuts are at an impasse.[5] Models that extrapolate current trends estimate that warming could reach 4°C by 2100.[6] Financing of adaptation measures also appears to be inadequate.[7]

As climate change forecasts become starker, consideration of CE has moved inward from the margins. The category is broad, encompassing numerous proposed methods whose means, goals, financial costs, response times, and risks vary widely, and whose boundaries with emissions abatement and adaptation are blurry.[8] Some methods would remove carbon dioxide from the atmosphere (CDR), whereas others would reduce incoming solar radiation (solar radiation management, or SRM) to counterbalance warming. In general, the former would be slower, more expensive, and less risky but address the cause of climate change more closely to its cause, whereas the latter would be faster, less expensive, and riskier, and address only the warming aspect of climate change.[9]

Because arguments against CE arise more often in the context of the riskier methods, we limit our focus in this article to larger-scale SRM methods such as stratospheric aerosol injection and marine cloud brightening. In these cases, models indicate they could counter a significant portion – and perhaps all – of global warming, although the effects would be regionally heterogeneous.[10] Models also point toward potential negative effects of SRM that may be significant but remain partially uncertain. Precipitation patterns will change.[11] The incoming light would be more diffuse while carbon dioxide would remain elevated, increasing plant primary productivity and altering ecosystems.[12] The leading candidate for stratospheric aerosol injection, sulphate particles, could damage the ozone layer.[13] Furthermore, because the current relevant question is whether to proceed with field tests, our discussion focuses on these more immediate steps, not on future potential SRM deployment.

4 Compare Nicholas Stern, *The Economics of Climate Change: The Stern Review* (Cambridge: Cambridge University Press, 2006), and Richard S. J. Tol, "The Economic Effects of Climate Change", 23 *Journal of Economic Perspectives* (2009), 29.

5 Kyoto Protocol to the United Nations Framework Convention on Climate Change, Kyoto, 10 December 1997, in force 16 February 2005, 37 *International Legal Materials* (1998), 22; Decision 2/CP.15, Report of the Conference of the Parties on Its Fifteenth Session, Held in Copenhagen from 7 to 19 December 2009. Addendum. Part Two: Action Taken by the Conference of the Parties at Its Fifteenth Session, UN Doc. FCCC/CP/2009/11/Add.1, 30 March 2010; International Energy Agency, *World Energy Outlook 2010* (Paris: International Energy Agency, 2010), at 45.

6 Richard A. Betts et al., "When Could Global Warming Reach 4°C?", 369 *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* (2011), 67.

7 United Nations Framework Convention on Climate Change, *Investment and Financial Flows to Address Climate Change* (Bonn: UNFCCC Secretariat, 2007).

8 An accessible review is John Shepherd et al., *Geoengineering the Climate: Science, Governance and Uncertainty* (London: The Royal Society, 2009).

9 Ocean fertilization is an exception, in that it presents much greater environmental risks than other proposed forms of carbon dioxide removal, and indeed our argument could be extended to this method. However, evidence increasingly points toward its limited capacity. Phillip Williamson et al., "Ocean Fertilization for Geoengineering: A Review of Effectiveness, Environmental Impacts and Emerging Governance", 90 *Process Safety and Environmental Protection* (2012), 475.

10 Juan B. Moreno-Cruz, Katharine L. Ricke, and David W. Keith, "A Simple Model to Account for Regional Inequalities in the Effectiveness of Solar Radiation Management", 110 *Climatic Change* (2012), 649.

11 *Ibid*.

12 Julia Pongratz et al., "Crop Yields in a Geoengineered Climate", 2 *Nature Climate Change* (2012), 101.

13 Patricia Heckendorn *et al*., "The Impact of Geoengineering Aerosols on Stratospheric Temperature and Ozone", 4 *Environmental Research Letters* (2009), 045108.

III. A *Prima Facie* Case for Climate Engineering Deployment

The benefits of research rest on whether SRM deployment may provide net benefits. This case need not be irrefutable. Indeed, too many unknowns remain, and the purpose of research is to reduce these unknowns. Therefore, we need to make only a *prima facie* case, i.e., we ask whether, at first appearance, SRM deployment could provide significant net benefits to humans and the environment under reasonable assumptions about a climate change future.

In short, most studies which use climatic and economic modelling indicate that SRM deployment would be highly beneficial under most circumstances. Early studies compared only the direct (and small) financial costs of SRM with the benefits of reducing climate change, but did not consider negative side effects.[14] More recent papers tried to incorporate such effects, as well as secondary benefits such as increased agricultural productivity due to diffuse light.[15] For example, one paper used the Dynamic Integrated Climate Change Model to consider both the beneficial and damaging effects of SRM. The authors found that when SRM supplements emissions abatement, it passes a cost-benefit test in a large majority, but not all, of the ranges of damages due to SRM, and of the probability that the SRM would be prematurely terminated.[16]

The greatest concern about the environmental effects of SRM is in the context of regional precipitation reductions predicted by some models.[17] The authors of a recent article used a climate model to calculate, for each of 22 terrestrial regions of the planet, damage functions that combined and equally weighed temperature and precipitation changes. The authors examined optimization scenarios under which the regions were alternatively weighted by area, population, and economic activity. The results demonstrated that under both Pareto optimal and potentially Pareto optimal scenarios, all regions benefitted significantly under climate change with SRM relative to climate change alone.[18]

The *capacity* to deploy SRM in an informed manner adds further value, independent of whether it actually is deployed. This is because the probability distribution of climate change damages has a long tail, in which there is a significant but low chance of very high damages. There are three reasons for this, each of which will not be known for decades due to the latency of climate change. First, climate sensitivity (the magnitude of climate change for a given amount of cumulative greenhouse gas emissions) may turn out to be greater than expected.[19] Second, climate change could induce a positive feedback loop, leading to non-linear climatic responses.[20] Third, an optimal abatement strategy may be unattainable due to the political demands of global collective action. Bearing in mind that some proposed SRM techniques may be rapidly effective, they could be deployed in response to learning about or actually experiencing the above possibilities.[21] In other words, the potential to deploy SRM is a form of insurance, and having such capacity would have a high value, especially – as we discuss below – from a precautionary perspective.

From these studies, we conclude that there is a reasonable chance that SRM deployment would significantly reduce the net damage from climate change to humans and the environment, and that

14 See, e.g., William D. Nordhaus, *A Question of Balance: Weighing the Options on Global Warming Policies* (New Haven: Yale University Press, 2008), at 20.

15 Juan B. Moreno-Cruz and Sjak Smulders, "Revisiting the Economics of Climate Change: The Role of Geoengineering", January 2010, available on the Internet at <http://works.bepress.com/morenocruz/4> (last accessed on 17 December 2012); Kjetil Gramstad and Sigve Tjøtta, "Climate Engineering: Cost Benefit and Beyond", 23 September 2010, available on the Internet at <http://mpra.ub.uni-muenchen.de/27302/> (last accessed on 17 December 2012).

16 J. Eric Bickel and Shubham Agrawal, "Reexamining the Economics of Aerosol Geoengineering", 119 *Climatic Change* (2013), 993, at Figure 8.

17 Alan Robock, Luke Oman, and Georgiy L. Stenchikov, "Regional Climate Responses to Geoengineering with Tropical and Arctic SO_2 Injections", 113 *Journal of Geophysical Research* (2008), D16101.

18 Moreno-Cruz et al., "Regional Inequalities", supra, note 10.

19 "[C]limate sensitivity [for a doubling of CO_2] is likely to be in the range of 2 to 4.5 °C with a best estimate of about 3 °C, and is very unlikely to be less than 1.5 °C. Values substantially higher than 4.5 °C cannot be excluded", see Intergovernmental Panel on Climage Change, *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva: Intergovernmental Panel on Climage Change, 2007), at 38.

20 Anthony D. Barnosky et al., "Approaching a State Shift in Earth's Biosphere", 486 *Nature* (2012), 52.

21 See Juan B. Moreno-Cruz and David W. Keith, "Climate Policy under Uncertainty: A Case for Solar Geoengineering", 2012, available on the Internet at <http://download.springer.com/static/pdf/547/art%253A10.1007%252Fs10584-012-0487-4.pdf?auth66=1380178945_3768b5c8233ff30fa349a93c91892dbf&ext=.pdf> (last accessed on 15 August 2013).

the capacity to deploy it under low probability, high impact scenarios will have great value.[22]

The costs of SRM research have two components. First, the direct costs of the research are small enough to be negligible relative to forecast climate change damages. Current proposed projects are on the order of hundreds of thousands of USD. Any proposed future budgets are rough conjectures. Nevertheless, one estimate is to increase funding to a magnitude of hundreds of millions USD annually for decades, yielding a total estimate on the order of tens of billions USD total.[23] Calculations of damages to humans and the environment, the second component, are likewise preliminary approximations. The first field tests, such as those now being proposed, pose no risks to humans and the environment. For example, one group of scientists planned on spraying seawater 1 km above the ocean in order to test delivery systems, and another proposes to inject very small amounts of light-scattering aerosols at a high altitude.[24] Clearly, further research would gradually scale up, posing small but increasing risks. Such proposed field projects can and should be carefully evaluated for their potential risks and benefits. Indeed, this may lead to a situation wherein risks outweigh benefits, and such projects should be aborted. The decisions faced now, though, are whether to proceed with small-scale field experiments that cost hundreds of thousands of USD with negligible risks.

Some observers have asserted that "geoengineering cannot be tested without full-scale implementation", however, and this would create unacceptable risks.[25] However, while it is true that moving from the laboratory to the field is a leap, by no means does this imply immediate full-scale deployment. For example, a recent paper described the important early role of analogue experiments and taking advantage of natural phenomena before commencing with experiments that perturb the environment.[26] Beyond that, projects can gradually increase in scale and potential impacts, and can be adaptively managed so that how and whether to proceed with subsequent stages is dependent upon prior results. Specifically, research could engage in "sustained science with small-scale field experiments. Early tests would focus on understanding processes. Later tests potentially could be large enough to produce barely detectable climate effects and reveal unexpected problems, but be small enough to limit risks."[27]

IV. Precaution

Precaution reflects recognition on the part of regulators of special properties of the environment and human health as object of regulation, even if this may result in false negatives. These include, in particular, the irreversible nature of much environmental damage, and the interests of future generations.

Precaution can be seen as a correction to existing legal systems. The principle arose from unease about the difficulty to legally engage threats to the environment or human health for which scientific evidence remained inconclusive, particularly in cases of new technologies or large scale interventions in the environment. In essence, precaution establishes legal competence to act where, if not for precaution, there would be no such competence.[28] Hence, precaution is an *empowering* principle, and may justify public action. Although there are numerous different articulations of the precautionary principle in circulation,[29] they have three elements in common: threats of harm, scientific uncertainty, and a possible precautionary action.

22 Although each of the authors of the above-cited papers made certain assumptions, without which their conclusions may have been different, these assumptions were not unreasonable.

23 Ken Caldeira and David W. Keith, "The Need for Climate Engineering Research", 27 *Issues in Science and Technology* (2010), 57.

24 Daniel Cressey, "Cancelled Project Spurs Debate over Geoengineering Patents", 485 *Nature* (2012), 429; Henry Fountain, "Trial Balloon: A Tiny Geoengineering Experiment", 17 July 2012, available on the Internet at <http://green.blogs.nytimes.com/2012/07/17/trial-balloon-a-tiny-geoengineering-experiment/> (last accessed on 6 March 2013); Lynn M. Russell et al., "E-Peace Eastern Pacific Emitted Aerosol Cloud Experiment", 2011, available on the Internet at <http://aerosols.ucsd.edu/E_PEACE.html> (last accessed on 6 March 2013).

25 Alan Robock et al., "A Test for Geoengineering?", 327 *Science* (2010), 530, at 530.

26 Lynn M. Russell et al., "Ecosystem Impacts of Geoengineering: A Review for Developing a Science Plan", 41 *AMBIO: A Journal of the Human Environment* (2012), 350.

27 Caldeira and Keith, "Climate Engineering Research", supra, note 23, at 62.

28 Han Somsen, "Cloning Trojan Horses: Precautionary Regulation of Reproductive Technologies", in Roger Brownsword and Karen Yeung (eds), *Regulating Technologies: Legal Futures, Regulatory Frames and Technological Fixes* (Oxford: Hart, 2008), 221.

29 Jonathan B. Wiener, "Precaution", in Daniel Bodansky, Jutta Brunnee, and Ellen Hey (eds), *The Oxford Handbook of International Environmental Law* (Oxford: Oxford University Press, 2007), 597.

In international law, the adoption of precaution in the Rio Declaration, and its incorporation in the Convention on Biological Diversity and the UN Convention on Climate Change (UNFCCC) signalled its widespread acceptance as a soft law norm.[30] The principle as such is not legally enforceable, but will typically be embedded in a concrete regulatory context, meaning that precaution often is enforceable. The empowering effect of precaution has been further operationalized through one or more of the constitutive elements of precaution. The totality of these elements instructs regulators to, inter alia:

a. recognize serious or irreversible harm;
b. acknowledge uncertainty;
c. apportion responsibilities to prove safety with regulatees;
d. stimulate public participation and deliberation;
e. consider alternative options;
f. respect the principle of proportionality;
g. ensure the provisional nature of measures;
h. monitor environmental performance.[31]

Precaution has substantially impacted multiple domains of environmental and human health law. Because the precautionary principle addresses risks to only humans and the environment, political and social risks, such as potentially reducing the political willpower toward emissions abatement and adaptation, fall outside the scope of precaution.[32] Although some of these concerns may be legitimate, they are not appropriate for the application of the precautionary principle and instead must be resolved through social, political, and legal pathways.

V. Precaution and Climate Engineering

Precaution has been invoked, both from within and outside academia, as part of a wider debate concerning CE.[33] Here we will discuss two important issues that have dominated this debate. The first is whether precaution could ever help guide CE decisions, considering the critique that the precautionary principle is incoherent since it can sometimes be argued to justify pursuing a particular approach, as well as prohibiting it.[34] In the context of climate engineering, it could simultaneously direct towards the employment and the prohibition of climate engineering, as both responses are characterized by uncertain risks for the environment and human health.

At least for the research phase, this is not the case. Precaution is a tool to deal with uncertain risks, but does not dictate an outcome. Although it is generally associated with banning certain products, activities, or technologies, in reality precautionary action has a variety of implications, potentially including warranting the use of, for example, a new technology to reduce risks.[35] Moreover, the elements noted above, such as proportionality and deliberation, should prevent arbitrary application of the principle.

The second issue concerns what guidance precaution may provide, particularly considering the problems of risk-risk trade-offs and potential catastrophes.[36] Hartzell-Nichols, for example, argues that if climate engineering creates new uncertain, potentially catastrophic risks, then its use – including research – should be rejected:

30 Rio Declaration on Environment and Development, UN Doc. A/CONF.151/26 (Vol. I), Principle 15; Convention on Biological Diversity, Rio de Janeiro, 5 June 1992, in force 29 December 1993, 31 *International Legal Materials* (1992), 818, Preamble, Para. 9; United Nations Framework Convention on Climate Change, Rio de Janeiro, 9 May 1992, in force 21 March 1994, 31 *International Legal Materials* (1992), 849, Art. 3.3.

31 Floor M. Fleurke, "Unpacking Precaution: A Study on the Application of the Precautionary Principle in Europe" (Ph.D. thesis on file at the University of Amsterdam, 2012), at 34 et seq.

32 See, e.g., Benjamin Hale, "The World That Would Have Been: Moral Hazard Arguments against Geoengineering", in Christopher J. Preston (ed.), *Engineering the Climate: The Ethics of Solar Radiation Management* (Lanham, Md.: Rowman and Littlefield, 2012), 113.

33 Bodansky, "May We Engineer the Climate?", supra, note 1; UK House of Commons Science and Technology Committee, *The Regulation of Geoengineering* (London: The Stationery Office, 2010), at 34–35; Kevin Elliott, "Geoengineering and the Precautionary Principle", 24 *International Journal of Applied Philosophy* (2010), 237 et seq.; CBD Decision, *supra* note 2; Jesse Reynolds, "The Regulation of Climate Engineering", 3 *Law, Innovation and Technology* (2011), 113, at 124; Ralph Bodle, "Geoengineering and International Law: The Search for Common Legal Ground", 46 *Tulsa Law Review* (2010), 305, at 309–311; Han Somsen, "When Regulators Mean Business", 40 *Rechtsfilosofie en Rechtstheorie* (2011), 47, at 55–56; Dorothee Amelung et al., "Beyond Calculation: Climate Engineering Risks from a Social Sciences Perspective", available on the Internet at <http://archiv.ub.uni-heidelberg.de/ojs/index.php/forum-mk/article/view/9408> (last accessed on 6 March 2013), at 25–41; Lauren Hartzell-Nichols, "Precaution and Solar Radiation Management", 15 *Ethics, Policy & Environment* (2012), 158 et seq.

34 Cass R. Sunstein, *Laws of Fear: Beyond the Precautionary Principle* (Cambridge: Cambridge University Press, 2005).

35 Imagine a scenario wherein there is a significant but uncertain chance that an asteroid may strike the Earth, with catastrophic results. Precaution would call for proactive steps, such as research into and development of technologies to prevent a disaster. See Richard Posner, *Catastrophe: Risk and Response* (Oxford: Oxford University Press, 2004).

36 Jonathan B. Wiener and John D. Graham (eds.), *Risk vs. Risk: Tradeoffs in Protecting Health and the Environment* (Cambridge, Mass.: Harvard University Press, 1995); Cass R. Sunstein, *Worst-Case Scenarios* (Cambridge, Mass.: Harvard University Press, 2007), at 144.

> [P]recautionary measures themselves prima facie should not pose new or further threats of catastrophe ... [I]f we believe we have moral reasons to avoid the threats of catastrophe posed by climate change we also have reasons to avoid the threats of catastrophe posed by any risky SRM strategies.[37]

Although it may seem to be morally ideal to attempt to avoid all potential catastrophes, this may simply not be the case with climate change given the serious consequences that unabated climate change may pose. Consequently, the above statement leads to paralysis, and likely suboptimal results with significant implications for humans and the environment.

Ideally, when applying precaution, regulators would adhere to a substitution clause that directs them to comparisons. In the case of climate engineering, this means that risks of climate change and risks of climate engineering would be compared with regard to their *relative* magnitude and scientific uncertainty.[38] It does not mean that a strategy that seeks to abate risks should be abandoned solely because it brings new, different risks to the table. Precaution can play a constructive mediating role in this kind of weighing exercise, where it is difficult to balance potential benefits and risks because of scientific uncertainty. Moreover, the presumption that maintaining the status quo takes priority over intentional change is a strong but refutable bias.[39] Notably, exhibiting bias in risk perception is particularly common concerning new technologies that seem beyond individual control and whose effects and not immediately perceptible.[40]

We conclude that a precautionary approach favours SRM research. There is scientific consensus on the risks of climate change: the Intergovernmental Panel on Climate Change Assessment Reports outlines extremely serious potential impacts of climate change. However, it is becoming increasingly clear also that climate policies, at least their current incarnation, will probably be ineffective in significantly reducing these risks.[41] On the other hand, current models indicate that SRM deployment would provide net reduction in both temperature and precipitation changes. Field trials would be smaller in scale and could be monitored for emerging risks, and will reduce uncertainty. The results might indicate lower risks for SRM than previously thought. Such research will not only indicate which climate engineering techniques have potential, but which ones might pose too much risk and should be taken off the table. Furthermore, if there is a feasible future scenario under which SRM will be deployed, research now will improve later decision making. This argument is bolstered by the results of a model of large-scale SRM field tests that indicated trade-offs among duration of the experiment, its intensity, and the certainty of its results.[42] Thus, beginning field research sooner rather than later will have the advantage of requiring less intense interventions in the environment in order to produce a given certainty of results. In addition to the insurance value of SRM knowledge, there is another feasible future scenario under which, for whatever reason, climate change imposes large negative impacts on humans and the environment. Under pressure, political leaders may demand that scientists do whatever they can, including SRM deployment, even if the uncertainties remain great. Precaution would call for those future scientists to know more.

VI. United Nations Framework Convention for Climate Change

Is there support in legally binding treaties for our argument that a precautionary approach favours SRM research? Although the UNFCCC, the most important text in international law concerning climate change, does not directly address CE, it does invoke precaution:

> The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible

37 Hartzell-Nichols, "Precaution and Solar Radiation Management", supra, note 33, at 166.

38 Posner, *Catastrophe*, supra, note 35; Sunstein, *Worst-Case Scenarios*, supra, note 36.

39 Daniel Kahneman, Jack L. Knetsch, and Richard H. Thaler, "The Endowment Effect, Loss Aversion, and Status Quo Bias", 5 *The Journal of Economic Perspectives* (1991), 193; Somsen, "Cloning Trojan Horses", supra, note 28, at 223.

40 Paul Slovic and Elke U. Weber, "Perception of Risk Posed by Extreme Events", Presentation at "Risk Management Strategies in an Uncertain World", Palisades, New York, 12 to 13 April 2002.

41 Intergovernmental Panel on Climage Change, *Fourth Assessment Report*, supra, note 19.

42 Douglas G. MacMynowski et al., "Can We Test Geoengineering?", 4 *Energy & Environmental Science* (2011), 5044.

damage, lack of full scientific certainty should not be used as a reason for postponing such measures taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.[43]

Although "lack of full scientific certainty" here is aimed at uncertainty related to climate change as such, since the UNFCCC was drafted the uncertainty regarding climate change has been reduced. Meanwhile, the potential effectiveness of a possible set of responses, SRM, remains greatly uncertain. It is reasonable to generalise the purpose of the precautionary principle as it is embodied in the UNFCCC – i.e. for scientific uncertainty to not be a barrier to taking measures – to imply support for at least exploring SRM through research. This reading is bolstered by two other considerations. First, the precautionary passage in the UNFCCC calls for responses to be cost-effective, and both SRM research and deployment appear to be remarkably inexpensive. Second, the UNFCCC calls for the development and diffusion of technology and research.[44] For example:

> All Parties ... shall ... Promote and cooperate in scientific, technological, technical, socio-economic and other research ... intended to further the understanding and to reduce or eliminate the remaining uncertainties regarding ... the economic and social consequences of various response strategies; [and p]romote and cooperate in the full, open and prompt exchange of relevant scientific, technological, [and] technical... information related to ... the economic and social consequences of various response strategies.[45]

VII. Conclusions

We have argued not only that precaution does not condemn SRM research, but that SRM research is in itself a precautionary response to the grave and potentially irreversible risks of climate change. This is not an argument for deployment, a decision that would require information presently unavailable. It is also not an argument to reduce efforts toward emissions abatement and adaptation. It simply means that in the face of potential climatic catastrophe, we should not postpone serious investigation into the capacity of SRM.

However, research itself should be organized and conducted in a precautionary manner. Specifically, this means that the elements noted above that constitute and operationalize precaution should become part of the risk assessment in the research phase.[46] Notably, some CE researchers and other scholars are working to further develop these principles as part of legitimate responsible oversight.[47] This is a crucial first step, as SRM, and CE in general, warrant both further research and appropriate regulation.

43 UNFCCC, supra, note 30, Art. 3.3.

44 Ibid., Art. 4.1, 4.3, 4.7, 4.8, 4.9, and 11.1.

45 Ibid., Art. 4.1(g) and (h). "Response strategies" is undefined, but presumably could include responses other than those encouraged by the UNFCCC.

46 See text to note 31.

47 Margaret S. Leinen, "The Asilomar International Conference on Climate Intervention Technologies: Background and Overview", 4 *Stanford Journal of Law, Science, and Policy* (2011), 1; Bipartisan Policy Center's Task Force on Climate Remediation, *Geoengineering: A National Strategic Plan for Research on the Potential Effectiveness, Feasibility, and Consequences of Climate Remediation Technologies* (Washington, DC: BPC, 2011); Steve Rayner et al., "The Oxford Principles", *Climatic Change* (2013), available on the Internet at <http://download.springer.com/static/pdf/874/art%253A10.1007%252Fs10584-012-0675-2.pdf?auth66=1380180336_dbb6694df2e5d5947c88a6088fe12f3e&ext=.pdf> (last accessed on 15 August 2013).

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The International Regulation of Climate Engineering: Lessons from Nuclear Power

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ABSTRACT

Proposals for climate engineering—intentional large-scale interventions in climate systems—are increasingly under consideration as potential additional responses to climate change, yet they pose risks of their own. Existing international regulation of large-scale field testing and deployment is considered inadequate. This article looks to the closest existing analogy—nuclear power—for lessons, and concludes that climate engineering research will most likely be promoted and will not be the subject of a binding multilateral agreement in the near future. Instead, climate engineering and its research will probably be internationally regulated gradually, with an initially low degree of legalisation, and through a plurality of means and institutions. This regulation is expected to proceed from norms, to non-binding and non-legal policies, and then to relatively soft multilateral agreements which emphasise procedural duties. Any eventual agreements will have trade-offs between their strength and breadth of participation. Intergovernmental institutions could play important facilitative roles. Treaties regarding liability and non-proliferation of global deployment capability should be considered.

KEYWORDS: climate engineering, climate change, geoengineering, nuclear power, international environmental law

1. INTRODUCTION

In the face of worsening forecasts for climate change and inadequate reductions of greenhouse gas emissions, intentional large-scale interventions in climate systems are now being considered as potential additional responses to reduce climate risks. Although at first glance these proposed 'climate engineering' or 'geoengineering' techniques may appear to be impractical, dangerous, and/or contrary to international environmental law, upon closer inspection some proposals may be effective in reducing the net climate risks to humans and the environment while receiving favourable consideration under international law. The movement of climate engineering discussions from the margins to the mainstream has been accompanied by the rise of a debate over the existing, and optimal, international regulation of climate engineering research and deployment.

This article looks to the international regulation of climate engineering's closest existing analogy—nuclear power—for lessons. It also aims to add a dose of realism to the climate engineering regulation discourse, which too often neglects what is actually possible in a world of sovereign states with diverse interests, capabilities, and levels of power, and too often focuses on climate engineering's risks while ignoring its potential benefits. Finally, the article maintains a distinction between climate engineering research and deployment, focusing on the more urgent question of the former while maintaining an awareness of the latter. The following section briefly introduces climate engineering, and notes that this article restricts itself to the riskier, poorly regulated climate engineering techniques. The third section presents nuclear power as an instructive case. The next section summarises the most important aspects of the international regulation of nuclear power, providing relevant observations. The final section draws appropriate inferences for the international regulation of climate engineering. It concludes that observers should be modest in their expectations of climate engineering's international regulation, particularly through binding multilateral agreements. Instead of implying that the international regulation of climate engineering and its research will be entirely lacking, it will more likely be gradual, with a low degree of legalisation, and through a plurality of means and institutions.[1] Although some may react to this with pessimism, I cautiously find the trajectory to be encouraging.

2. CLIMATE CHANGE AND CLIMATE ENGINEERING

Considered in isolation, suggestions that humans could intentionally alter the climate appear unjustified and possibly contrary to international law. However, because climate engineering is proposed as a means to counter the most dangerous aspects of anthropogenic climate change, it must be considered in that context. Industrial activities have altered the atmospheric concentrations of some 'greenhouse gases', which allow sunlight to enter the atmosphere but restrict heat from exiting it. The most important of these is carbon dioxide, whose concentration has increased in the past two centuries by roughly 40% due to processes such as burning of fossil fuels and land-use changes.[2] These increases in greenhouse gas concentrations will change the climate by warming it and altering precipitation patterns, harming humans and the environment in the process.[3] To date, there have been two leading categories of internationally coordinated efforts to reduce climate change risks: to limit and reduce

1 'Legalization' in the sense of greater obligation, precision, and/or delegation. See Kenneth Abbott and others, 'The Concept of Legalization' (2000) 54 Int'l Org 401.

2 Thomas Stocker and others (eds), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (CUP 2014) 11.

3 Christopher Field and others (eds), *Climate Change 2014: Impacts, Adaptation, and Vulnerabilities. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (CUP 2014).

greenhouse gas emissions, and to adapt society and ecosystems to a changed climate.[4] Efforts toward emissions reductions and adaptation have thus far been disappointing, and there are reasons to be pessimistic about the future. Furthermore, scientists remain uncertain as to the magnitude of climate change risks, in part because climate change is delayed by several decades relative to greenhouse gas emissions. Meanwhile, the intensity of climate change as a function of greenhouse gas concentrations and its damage to humans and the environment as a function of climate change are not perfectly known. Therefore, we are already committed to a yet unknown amount of climate change, and there is a significant chance that the damage may be much worse than the simple expected value.[5]

In response to climate change risks and the limited prospects for emissions reductions and adaptation, some scientists and other observers are increasingly discussing intentional large-scale interventions in the planet's climate systems as potential additional responses.[6] There are two distinct categories of such 'climate engineering' or 'geoengineering', the first of which would pull carbon dioxide from the atmosphere (carbon dioxide removal or negative emissions technologies). These proposals would be relatively slow, expensive, and low risk while addressing a cause of climate change. A significant exception to the low-risk character of these proposals is ocean fertilisation. In this, a nutrient would be added to the ocean, instigating an algal bloom. The algae indirectly incorporate atmospheric carbon dioxide into their bodies, some of which would sink to the deep ocean after their death, effectively sequestering the carbon. Ocean fertilisation presents risks, such as generating other greenhouse gases as by-products and depriving nearby marine areas of nutrients.

The second category of climate engineering proposals, collectively called solar radiation management (SRM), would attempt to make the planet slightly more reflective in order to compensate for the warming aspect of climate change. These would be relatively fast, inexpensive, and high risk, and only address a symptom of climate change. Under the most widely discussed technique, a reflective aerosol would be injected into the stratosphere, mimicking the global cooling effect experienced after major volcanoes. Another would involve the lower atmospheric spraying of seawater mist, which after evaporation would result in small salt particles in the air. These would act as cloud condensation nuclei, in turn making marine clouds more reflective.

The vast majority of those who research climate engineering assert that it would not be a substitute for emissions reductions or adaptation. Instead they emphasise the primacy of emissions reductions, hope that climate engineering would never be deployed, and see emissions reductions, adaptation, and climate engineering

4 These categories are enshrined in the United Nations Framework Convention on Climate Change (UNFCCC) (adopted 9 May 1992, entered into force 21 March 1994) 1771 UNTS 107, arts 4.1, 4.2.

5 That is, the probability distribution of damage is not symmetrical, but instead has a 'long tail' of low probability, high-impact damage.

6 A good non-technical introduction is John Shepherd and others, *Geoengineering the Climate: Science, Governance and Uncertainty* (The Royal Society 2009). A more recent, detailed review is Tim Lenton and Naomi Vaughan (eds), *Geoengineering Responses to Climate Change: Selected Entries from the Encyclopedia of Sustainability Science and Technology* (Springer 2013). Climate engineering received a prominent but cautious discussion in the latest report of the Intergovernmental Panel on Climate Change (IPCC). Stocker and others (eds) (n 2) SPM-21 and ss 6.5, 7.7.

(if necessary) as complementary. For example, the first 'headline message' and 'key recommendation' of a seminal report from the Royal Society are, respectively,

> The safest and most predictable method of moderating climate change is to take early and effective action to reduce emissions of greenhouse gases. No geoengineering method can provide an easy or readily acceptable alternative solution to the problem of climate change.... Parties to the UNFCCC should make increased efforts towards mitigating and adapting to climate change, and in particular to agreeing to global emissions reductions.[7]

On this view, carbon dioxide removal would decelerate and then reduce its atmospheric concentration. SRM would be a temporary means to reduce harm to humans and the environment until greenhouse gas concentrations have been reduced and/or society has adapted. Another perspective holds that climate engineering, particularly SRM, could be developed and held as something of an insurance option in case climate change turns out to be worse than expected.

The environmental and social risks of climate engineering would vary among the proposed techniques and also by the stages of their development. Some observers fear that the mere discussion of climate engineering could decrease the political willpower for emissions abatement and adaptation.[8] Researching climate engineering could lead to technological momentum and the development of influential vested interests, both of which could cause biases in favour of which technique(s), if any, are actually deployed in future. Large-scale field research and deployment may have unintended negative side effects to humans and the environment, in particular changes in precipitation. Because some effects may be at least partially known but not intended, climate engineering field research or deployment could raise questions of informed consent of those who will be impacted.[9] Deployment could pose issues of control, decision-making, and disagreement among states.[10] Some SRM methods could be inexpensive enough to be globally deployed for tens of billions of dollars, within the budget of small states as well as some non-state organisations and individuals.[11] Perhaps the greatest risk would be if, once deployed, SRM were to stop for some reason, causing the climate change that would have occurred in the absence of SRM to occur in less than a year. This very rapid rate of climate change would cause much greater damage relative to 'normal' climate change.

Because many of these risks are transboundary and/or would occur in areas beyond national jurisdiction, international environmental law is relevant for climate engineering.

7 Shepherd and others (n 6) ix.

8 Albert Lin, 'Does Geoengineering Present a Moral Hazard?' (2013) 40 Ecol LQ 673.

9 David Morrow, Robert Kopp and Michael Oppenheimer, 'Toward Ethical Norms and Institutions for Climate Engineering Research' (2009) 4 Envtl Res Lett 045106.

10 In reality, international tensions regarding climate engineering deployment may not be so strong because, according to models, the world's regions may agree more than not as to the desired intensity of climate engineering. See Katharine Ricke, Juan Moreno-Cruz and Ken Caldeira, 'Strategic Incentives for Climate Geoengineering Coalitions to Exclude Broad Participation' (2013) 8 Envtl Res Lett 014021.

11 Realistically, implementation costs, the inability to carry it out undetected, and the probability of retaliation make unilateral deployment unlikely. Scott Horton, 'Geoengineering and the Myth of Unilateralism: Pressures and Prospects for International Cooperation' (2011) 4 Stan JL Sci & Pol'y 56; Edward Parson and Lia Ernst, 'International Governance of Climate Engineering' (2013) 14 Theo Inq L 307, 332–33.

I have argued elsewhere that, on the whole, existing international environmental law leans in favour of climate engineering research as developing potential means toward reducing risks to humans and the environment.[12] One reason for this is because, even though climate engineering poses some risks, those from climate change are of a much higher order.[13] Additionally, some multilateral environmental agreements encourage science and technology, and climate engineering and its research are also consistent with principles of international environmental law including the polluter pays principle, the principle of common but differentiated responsibilities, and the precautionary principle.[14] Moreover, those agreements whose substance is most closely related to climate engineering are best interpreted as being favourable to it. Some existing multilateral environmental agreements do impose certain duties, mainly procedural ones, on states that might carry out, or be responsible for, climate engineering. These duties are part of, or roughly consistent with, the customary international law of transboundary risks. A handful of specific climate engineering activities are prohibited or curtailed.[15]

There is a consensus that existing international regulation—broadly defined—of climate engineering is inadequate. To date, the academic literature discussing this regulatory gap has been rather general in its nature, suggesting guideposts on the path toward some form of international regulation. The positions in this discourse can be generalised as varying in at least two dimensions.[16] First, some observers believe that the regulation of climate engineering and its research should be developed through existing international legal institutions.[17] The most-cited forum is the Conference of Parties to the UN Framework Convention on Climate Change (UNFCCC-COP), which could possibly work towards a new Protocol to the UNFCCC. Others argue that such forums would be unproductive and likely lead to stalemate or to premature, poorly crafted binding rules.[18] Instead, these writers often

12 Jesse Reynolds, 'Climate Engineering Field Research: The Favorable Setting of International Environmental Law' (2014) 5 Wash & Lee J Energy, Clim & Environ (forthcoming).

13 Juan Moreno-Cruz, Katharine Ricke and David Keith, 'A Simple Model to Account for Regional Inequalities in the Effectiveness of Solar Radiation Management' (2012) 110 Clim Change 649. Consider that both climate change and climate engineering may satisfy the definitions of 'pollution', 'adverse effect' or 'damage' which multilateral environmental agreements seek to reduce. More general obligations to protect the environment further support climate engineering research. For details, see Reynolds (n 12).

14 Jesse Reynolds and Floor Fleurke, 'Climate Engineering Research: A Precautionary Response to Climate Change?' (2013) Carbon Clim L Rev 101.

15 For treaty details, see Reynolds (n 12).

16 Of course, the positions are rarely at the extremes of the suggested axes and often cannot be placed on a clear, single 'location'.

17 Scott Barrett, 'The Incredible Economics of Geoengineering' (2008) 39 Envtl & Resour Econ 45, 53; Albert Lin, 'Geoengineering Governance' (2009) 8 Issues Legal Schol, 17–26; Karen Scott, 'International Law in the Anthropocene: Responding to the Geoengineering Challenge' (2013) 34 Mich J Int'l L 309, 355; Michael Zürn and Stefan Schäfer, 'The Paradox of Climate Engineering' (2013) 4 Glob Pol'y 266, 273.

18 Daniel Bodansky, 'May We Engineer the Climate?' (1996) 33 Clim Change 309, 319; David Victor, 'On the Regulation of Geoengineering' (2008) 24 Oxford Rev Econ Pol'y 322, 331–32; William Daniel Davis, 'What Does "Green" Mean?: Anthropogenic Climate Change, Geoengineering, and International Environmental Law' (2009) 43 Ga L Rev 901, 928–38; David Victor and others, 'The Geoengineering Option: A Last Resort Against Global Warming?' (2009) 88 Foreign Aff 64, 75; David Keith, Edward Parson and M Granger Morgan, 'Research on Global Sun Block Needed Now' (2010) 463 Nature 426, 427; Richard Elliot Benedick, 'Considerations on Governance for Climate Remediation Technologies: Lessons from the "Ozone Hole"' (2011) 4 Stan JL Sci Pol'y 6, 7–8; Parson and Ernst (n 11) 324.

emphasise the benefits of initially developing norms from the bottom-up,[19] coordinating scientific activities (perhaps through central institutions),[20] and a well-crafted moratorium on deployment and research projects above a certain threshold.[21] As a second dimension of variability, some scholars believe that many countries should be brought into forums for developing international regulation—whatever their nature—as early as possible,[22] whereas a counter position is that a smaller group of states would be more effective.[23]

This article is concerned chiefly with those proposed climate engineering methods that may be effective and affordable yet pose significant risks. This presently includes SRM techniques such as stratospheric aerosol injection and marine cloud brightening, although this set could change over time. Even though carbon dioxide removal by ocean fertilisation could arguably be included, it appears to now be fairly well regulated,[24] a recent incident notwithstanding.[25] Therefore, from here onward, 'climate engineering' will refer only to these relatively riskier, weakly regulated SRM methods.

19 Victor (n 18) 332–33; Davis (n 18) 941–42; Victor and others (n 18) 74; Keith, Parson and Morgan (n 18) 427; Lisa Dilling and Rachel Hauser, 'Governing Geoengineering Research: Why, When and How?' (2013) 121 Clim Change 553; M Granger Morgan, Robert R Nordhaus and Paul Gottlieb, 'Needed: Research Guidelines for Solar Radiation Management' (2013) 29 Issues Sci Tech 37, 41–43; Parson and Ernst (n 11) 324–25; Stefan Schäfer and others, 'Field Tests of Solar Climate Engineering' (2013) 3 Nature Clim Change 766.

20 Victor (n 18) 332–33; Davis (n 18) 940–44; Victor and others (n 18) 73–74; John Virgoe, 'International Governance of a Possible Geoengineering Intervention to Combat Climate Change' (2009) 95 Clim Change 103, 116–17; Keith, Parson and Morgan (n 18) 427; Benedick (n 18); Daniel Bodansky, 'Governing Climate Engineering: Scenarios for Analysis' (2011) 11–47 The Harvard Project on Climate Agreements Discussion Papers, 29; Dilling and Hauser (n 19).

21 Ralph Cicerone, 'Geoengineering: Encouraging Research and Overseeing Implementation' (2006) 77 Clim Change 221; Davis (n 18) 944–45; Morgan, Nordhaus and Gottlieb (n 19) 41–42; Edward Parson and David Keith, 'End the Deadlock on Governance of Geoengineering Research' (2013) 339 Science 1278, 1279.

22 Bodansky (n 18) 320. This implicitly also includes those who propose action through the UNFCCC (n 17), which has universal participation.

23 Victor (n 18) 332; Davis (n 18) 938–40; Benedick (n 18); Parson and Ernst (n 11) 333–34.

24 The Contracting Parties to the London Convention and London Protocol, which regulate marine dumping, developed (and continue to refine) regulations for marine geoengineering permitting only 'legitimate scientific research'. The parties have approved amendments to the London Protocol in order to make this binding. 'Resolution LC-LP.1 on the Regulation of Ocean Fertilization' (2008) in 'Report of the Thirtieth Consultative Meeting and the Third Meeting of Contracting Parties' (2008) IMO Doc LC 30/16; 'Resolution LC-LP.2 on the Assessment Framework for Scientific Research Involving Ocean Fertilization' and 'Assessment Framework for Scientific Research Involving Ocean Fertilization' in 'Report of the Thirty-Second Consultative Meeting and the Fifth Meeting of Contracting Parties' (2010) IMO Doc LC 32/13; 'Resolution LP.4(8) on the Amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities' in 'Report of the Thirty-Fifth Consultative Meeting and the Eighth Meeting of Contracting Parties (2013) IMO Doc LC 35/15.

25 A 'rogue' scientist performed the largest ocean fertilization experiment to date with the purported intentions of restoring salmon and somehow selling carbon credits in order to fund the project. The Canadian government is currently investigating. See Neil Craik, Jason Blackstock and Anna-Maria Hubert, 'Regulating Geoengineering Research through Domestic Environmental Protection Frameworks: Reflections on the Recent Canadian Ocean Fertilization Case' (2013) Carbon Clim L Rev 117.

3. THE NUCLEAR POWER ANALOGY

The academic discourse discussed above has emphasised the challenging novelties of regulating climate engineering. In this, most authors have referred to previous new risky technologies only in passing and have drawn few useful lessons from them.[26] This is a missed opportunity, and I detail six reasons that nuclear power generation and its attendant risks provide the best existing case in international law from which to draw insights into the potential international regulation of climate engineering and its research. First, both nuclear power and climate engineering present transboundary risks to human health and the environment. An accident at a nuclear power installation can result in dangerous levels of radiation in other countries and non-state areas. This was most evident in the 1986 Chernobyl accident, which occurred in the Soviet Union and contaminated parts of about a dozen other countries. Similarly, large-scale climate engineering field research projects and deployment will threaten the environments of other states and non-state areas in ways that remain partially unknown. The most significant risks are changes in rainfall patterns and in sunlight characteristics due to SRM, in turn impacting ecosystems and agriculture.[27] Larger environmental changes caused by SRM are not out of the question.[28]

Second, the risks posed by nuclear power and climate engineering are ultra-hazardous, in that they carry low probabilities of very high damage.[29] To date, the vast majority of deaths due to nuclear power generation have occurred as a result of only two accidents, Chernobyl and Fukushima in 2011, which together led to dozens of direct deaths and thousands of indirect ones.[30] The risk of much greater damage, such as from larger accidents or terrorism, is uncertain. In the case of climate engineering, potentially catastrophic hazards include major changes in precipitation and light, and perhaps even alterations in major global phenomena such as the El Niño/La Niña-Southern Oscillation.[31] These ultra-hazardous risks are difficult to manage because of the long durations between negative events. As a result, little empirical data is available, causing great uncertainty in any cost-benefit analysis.[32] Furthermore, the choice of an intergenerational discount rate has a dramatic effect

26 Eg Barrett (n 17) 51–53, Victor (n 18) 332, and Bodansky, 'Governing Climate Engineering: Scenarios for Analysis' (n 20) 24 briefly mention the European Organization for Nuclear Research and its Large Hadron Collider. Nuclear safety or weapons were brought up by Bodansky, 'May We Engineer the Climate?' (n 18) 318; Victor (n 18) 328; Virgoe (n 20) 112; Bidisha Banerjee, 'The Limitations of Geoengineering Governance in a World of Uncertainty' (2011) 4 Stan JL Sci & Pol'y 15, 32–33.

27 Simone Tilmes and others, 'The Hydrological Impact of Geoengineering in the Geoengineering Model Intercomparison Project (GeoMIP)' (2013) 18 J Geophys Res 11036; J Pongratz and others, 'Crop Yields in a Geoengineered Climate' (2012) 2 Nat Clim Change 101.

28 Peter Braesicke, Olaf Morgenstern and John Pyle, 'Might Dimming the Sun Change Atmospheric ENSO Teleconnections as We Know Them?' (2011) 12 Atmos Sci Lett 184.

29 Other ultra-hazardous activities in international law are maritime oil transportation, space activities, and activities involving hazardous substances. See Hanqin Xue, *Transboundary Damage in International Law* (CUP 2003) 19–72.

30 Chernobyl Forum, 'Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine' <http://www.iaea.org/Publications/Booklets/ss.html> 14, 16; John Ten Hoeve and Mark Jacobson, 'Worldwide Health Effects of the Fukushima Daiichi Nuclear Accident' (2012) 5 Energy Environ Sci 8743.

31 (n 27–28).

32 See eg Martin Weitzman, 'On Modeling and Interpreting the Economics of Catastrophic Climate Change' (2009) 91 Rev Econ Stat 1.

on cost and benefit estimates but is ethically ambiguous.[33] Moreover, if centuries-long trends continue, then future generations will most likely have greater capacities to adapt to negative events. Future generations will also probably have different values concerning, among other things, risk aversion, equity, and the values of biodiversity and 'undisturbed nature' versus the well-being of people. Finally, costly efforts to reduce low-probability risks that are infrequent or have not yet happened are usually politically unpopular, limiting action by political leaders in democratic states.[34]

The third basis for an analogy between nuclear power and climate engineering is that both present risk–risk tradeoffs, in which the reduction of targeted risks creates a new set of countervailing risks. Nuclear power is a substitute for the burning of fossil fuels, which causes deaths and illness in the short term and climate change in the long term. One recent study placed the benefits to date of the existing capacity of nuclear power relative to the use of fossil fuels at 1.84 million prevented air-pollution deaths and two years' worth of averted global greenhouse gas emissions.[35] In the case of climate engineering, it may be able to greatly reduce climate change risks to humans and the environment, while posing some risks of its own. These risk–risk tradeoffs are difficult to manage in that the two sets of risks may be of fundamentally different types and/or affect different populations or ecosystems.[36] Applying traditional legal norms, especially precaution, becomes very difficult under these circumstances.

Fourth, although the politics of climate engineering presently remain amorphous, they are likely to emerge in a similar pattern as that of nuclear power. Among the general population, nuclear power has been, and climate engineering probably will be, perceived as unknown, dreadful and involuntary, characteristics that are correlated with strong aversion.[37] Among political leaders, nuclear power has been, and climate engineering probably will be, developed in the context of potential dual-use

33 The discount rate is the quantification of people's preference for receiving rewards sooner rather than later (and for incurring losses later rather than sooner). This is problematic when considering subsequent generations. On one hand, intergenerational discounting amounts to transferring costs onto another population cohort (ie, the future) which lacks a voice in present decision-making processes, while those with a voice reap the benefits. On the other hand, using an intergenerational discount rate of zero also produces perverse results. For example, all but the most essential current consumption would be unjustified, and instead nearly all present resources would be invested in future generations, even though they will be wealthier than us. See Paul Portney and John Weyant (eds), *Discounting and Intergenerational Equity* (Resources for the Future 1999).

34 Although support for action against climate change is popular in the abstract, it is low when it competes with other objectives. Eg, in an American annual survey, 'dealing with global warming' has been last or second-to-last among 15–20 public policy priorities since its inclusion in 2007. The Pew Research Centre for People and the Press, Twelve Years of the Public's Top Priorities (2013) <http://www.people-press.org/interactives/top-priorities> accessed 7 November 2013.

35 Pushker Kharecha and James Hansen, 'Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power' (2013) 47 Environ Sci Tech 4889.

36 John Graham and Jonathan Baert Wiener, 'Confronting Risk Tradeoffs' in John D Graham and Jonathan Baert Wiener (eds), *Risk vs Risk: Tradeoffs in Protecting Health and the Environment* (Harvard UP 1995) 19–41.

37 Paul Slovic, 'Perception of Risk' (1987) 236 Science 280; Ellen Peters and Paul Slovic, 'The Role of Affect and Worldviews as Orienting Dispositions in the Perception and Acceptance of Nuclear Power' (1996) 26 J Appl Soc Psychol 1427; Adam Corner and others, 'Messing with Nature? Exploring Public Perceptions of Geoengineering in the UK' (2013) 23 Glob Envtl Change 938. See also Dan Kahan and others, 'Geoengineering and the Science Communication Environment: A Cross-Cultural Experiment' (2012) The Cultural Cognition Project Working Paper 92 <http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1981907> accessed 10 October 2013.

and highly heterogeneous state capacity. Specifically, nuclear power is internationally promoted, but can be used as a basis for nuclear weapons programmes, which the nuclear powers desire to limit to themselves.[38] Similarly, climate engineering research appears to be encouraged by existing international environmental law, and can be expected to be pursued by states.[39] And as with nuclear weapons, countries' relative power will be impacted by their acquisition of an ability to deploy large scale climate engineering. Those states with this capacity will wish to prevent inappropriately risky, premature, or militarised implementation and, will also most likely, wish to prevent its proliferation to a greater number of states in order to maintain their relatively greater power.

Fifth, scientists and technological expertise play a necessary role in the regulation of nuclear power and climate engineering. Of course, environmental law cannot be disentangled from the science on which it is based. Regulators must rely upon technical experts and their specialised knowledge due to the complex and dynamic nature of certain issues. In turn, these experts can form close-knit communities that are influential in establishing norms and shaping policy.[40] Expertise is also used as a means to establish and maintain legitimacy, particularly within regulated domains—such as nuclear power and climate engineering—that pose uncertainty and/or complexity and that cross lines between states and among international, national, quasi-public, and private institutions.[41] Indeed, '[i]n emerging areas of international law concerned with the regulation of risk, expertise based on scientific and technical knowledge is typically viewed as a plausible basis for legitimating the growing authority exercised by relevant international rules'.[42] Of course, these experts are also likely to be practitioners, and thus to the extent that they influence regulation, it partially takes on the form of self-regulation. This brings both benefits and challenges. In addition to greater knowledge and legitimacy, the inclusion of the regulated actors in the development, monitoring, and enforcement of regulation can make it more effective due to less adversarial relationships between the regulators and regulated. This is also the case when it is difficult for consumers to learn about the quality of a product before purchasing it, and when the producers' reputations are important, sensitive, and shared.[43] In the cases of

38 The peaceful development of nuclear technologies and the prevention of nuclear weapon proliferation are the foundations of international nuclear law. Statute of the International Atomic Energy Agency (opened for signatures 26 October 1956, entered into force 29 July 1957) 26 UNTS 3, arts II, III; Treaty on the Non-Proliferation of Nuclear Weapons (opened for signatures 1 July 1968, entered into force 5 March 1970) 729 UNTS 161 (Non-Proliferation Treaty) arts IV, V.

39 Text to (n 13–15).

40 Although nuclear power scientists and engineers appear to meet Haas's criteria for an epistemic community, he asserts that they enjoy less political influence because their research is expensive and thus less independent of their funding source. Peter Haas, 'Epistemic Communities' in Daniel Bodansky, Jutta Brunnée and Ellen Hey (eds), *The Oxford Handbook of International Environmental Law* (OUP 2007) 763–65.

41 Daniel Bodansky, 'The Legitimacy of International Governance: A Coming Challenge for International Environmental Law?' (1999) 93 Am J Int'l L 596, 601; Gráinne de Búrca, 'Developing Democracy Beyond the State' (2008) 36 Colum J Transnat'l L 221, 240–46.

42 Jacqueline Peel, *Science and Risk Regulation in International Law* (CUP 2010) 14.

43 Thomas Gehrig and Peter-J Jost, 'Quacks, Lemons, and Self Regulation: A Welfare Analysis' (1995) 7 J Reg Econ 309; Andrew King, Michael Lenox and Michael Barnett, 'Strategic Responses to the Reputation Commons Problem' in Andrew Hoffman and Marc Ventresca (eds), *Organizations, Policy and the Natural Environment: Institutional and Strategic Perspectives* (Stanford University Press 2002).

nuclear power and climate engineering, the 'consumers' can include the government agencies which approve and fund the activities and the voters who lend support, the 'quality of the product' includes the generated risks, 'purchasing' is done through grants or regulatory approval, and the 'producers' are energy companies or climate engineering researchers. On the other hand, the self-regulated can use their position for rent-seeking behaviour, at the expense of both the public and potential competing 'producers'. Yet regulatory regimes are rarely pure self-regulation, with a spectrum of hybrid forms and roles for the regulated actors available.

The final basis for a nuclear power–climate engineering analogy is that the regulations of the two technologies present similar problem structures. Both nuclear power and climate engineering research are, in some aspects, global public goods.[44] The former is one in that it is a substitute for the burning of fossil fuels.[45] From this, the world benefits from reductions in greenhouse gas emissions, even though the country hosting nuclear power bears the costs, including the environmental risks. Similarly, climate engineering research can increase shared knowledge of possible additional responses to climate change, while the costs are borne by few.[46] Notably, both are positive only to the extent that they reduce the negative effects of another global public 'good', greenhouse gas emissions. More specifically, the emissions-reducing aspect of nuclear power and climate engineering research are aggregate effort global public goods,[47] whose supply is a function of worldwide cumulative efforts, and both are promoted in international law.[48] Scott Barrett concludes that international cooperation—generally through multilateral agreements—is useful in the promotion of global public goods in order to coordinate efforts, share costs, tap potential where local capacity may be lacking (such as in developing countries), and overcome free-riding.[49] This international cooperation need not be global, because non-participating states do not hinder the provision of the good, although they may unjustly free-ride on its provision by others.

At the same time, nuclear power and climate engineering research each increase the likelihood of events with large negative effects: the former could lead to

44 A public good is something which is non-rivalrous and non-excludable. Its effects can be positive or negative for various people or states. See Daniel Bodansky, 'What's in a Concept? Global Public Goods, International Law, and Legitimacy' (2012) 23 Eur J Int L 651. Of course, public goods also often also confer private benefits.

45 Text to (n 35).

46 Scientific research and accessible knowledge in general are public goods. Doinique Foray, *The Economics of Knowledge* (MIT Press 2004) 113–29. Research as a public good assumes that the results are published and not subject to extensive intellectual property claims. Recently proposed norms for climate engineering research call for transparency, open publication of positive and negative results, and/or no private intellectual property. Michael MacCracken and others, *The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques* <http://climateresponsefund.org/> accessed 19 November 2013; Jane Long and others, *Geoengineering: A National Strategic Plan for Research on the Potential Effectiveness, Feasibility, and Consequences of Climate Remediation Technologies* <http://bipartisanpolicy.org/library/report/task-force-climate-remediation-research> accessed 19 April 2013; Steve Rayner and others, 'The Oxford Principles' (2013) 121 Clim Change 499.

47 See the distinction among single best efforts, weakest links, and aggregate efforts in Jack Hirshleifer, 'From Weakest-link to Best-shot: The Voluntary Provision of Public Goods' (1983) 41 Pub Choice 371; Scott Barrett, *Why Cooperate? The Incentive to Supply Global Public Goods* (OUP 2007).

48 (n 38); text to (n 13–15).

49 Barrett (n 47), ch 3.

accidents, terrorism, and weapons proliferation, while the latter makes inappropriately risky, premature, or militarised climate engineering deployment possible. Efforts to *prevent* these negative events are mixtures of weakest link global public goods, whose provision depends upon the state with the weakest performance, and mutual restraint, in which all states must refrain from doing something.[50] Barrett argues that international coordination is needed in these cases in order to establish standards and sometimes to share costs, but that multilateral agreements are less useful than with aggregate effort global public goods. Instead, norms, consensus and customary law can better provide incentives to those laggard states that may not otherwise have the incentives to join a multilateral agreement.[51] Notably, in the two cases here, the desire to prevent negative events is particularly acute among the advocates and practitioners of the technology. This is because the reputations of the individual actors (ie nuclear power providers or climate engineering researchers) are important and sensitive due to the controversial nature of their practice, and require a social license to operate.[52] However, the actors are relatively small in number and their identities are not clearly distinguished by members of the public. Consequently they share a reputations 'common'.[53] Since these actors are few in number, they may be able to cooperate in order to maintain their shared reputation.[54]

Of course, nuclear power and climate engineering differ in important ways. The risks of nuclear power are known, and power plants can reasonably strive for negligible harm to humans and the environment, whereas climate engineering inherently will have some unknown risks—at least initially—and will impact the environment. When nuclear accidents do occur, the negative effects are regional and of a limited type, while those from climate engineering deployment could be global and could take a wide range of forms. At the same time, the benefits of climate engineering research (and perhaps deployment) would be more clearly, and probably more widely distributed, than the benefits of nuclear power. Furthermore, nuclear power is a relatively consistent practice year-to-year, whereas climate engineering research would be more dynamic, changing in light of previous results. Relatively speaking, determining causation of damages is easier with nuclear power because of radioactive isotopes' traceability, the predictability of radioactive materials' movement and lifespan, and better knowledge of radiation's effects, while the precise impact of a climate engineering field experiment may be difficult to pinpoint. Finally, the line between promoted and proscribed applications is clearer in the case of nuclear technologies. Nevertheless, some useful insights from experience with the existing technology of nuclear power can be drawn.

50 See n 47.

51 Barrett (n 47) chs 2, 5.

52 Neil Gunningham, Robert Kagan and Dorothy Thornton, 'Social License and Environmental Protection: Why Businesses Go Beyond Compliance' (2004) 29 L & Soc Inquiry 307.

53 Consider the reactions among the public and politicians around the world to nuclear accidents such as Three Mile Island, Chernobyl, and Fukushima. Matthew Fuhrmann, 'Splitting Atoms: Why Do Countries Build Nuclear Power Plants?' (2012) 38 Int'l Interact 29.

54 King, Lenox and Barnett (n 43).

4. THE REGULATION OF NUCLEAR POWER

The international regulation of nuclear power is vast, but here, a few relevant observations will suffice. These are based primarily on international regulation concerned with reducing the risks of accidents at civilian nuclear power facilities, including both ex ante accident prevention and ex post accident response. However, the basis for these observations extends to international regulation of nuclear weapons proliferation, because nuclear power and climate engineering research are each promoted while the proliferation of nuclear weapons and the risky, premature, or militarised deployment of climate engineering are widely condemned.

It is both obvious yet noteworthy that nuclear power, perhaps the riskiest of the ultra-hazardous activities recognised under international law, is not illegal. Indeed, it is actively promoted under international law[55] and the 'research, production and use of nuclear energy for peaceful purposes' constitute an 'inalienable right' of states.[56] Instead, like other transboundary risks, nuclear power must be carried out with due diligence, which in this case includes among other things national regulation consistent with globally promulgated standards, prior assessment, notification and international peer review. This is evident in the 1994 Convention on Nuclear Safety, the first and most important binding international law regarding the safety standards of civilian nuclear power facilities.[57] Parties are obligated to 'take the appropriate steps to ensure' that general standards regarding—among other things—the siting, design, construction, and operation of nuclear installations; emergency preparation; funding for the safety of nuclear facilities; and training of staff.[58] Parties must maintain a domestic regulatory framework that establishes safety standards, issues licenses, inspects installations and enforces the regulations.[59] The Convention also calls for its parties to issue reports on their progress for peer review meetings.[60]

Second, states generally prefer to retain sovereignty, and this preference is stronger the closer an issue is to national security. This is most apparent in the case of nuclear weapons, in which states such as China, France, India, Israel and the USA have refused to join widely adopted agreements and/or have rejected the decisions of international courts when these agreements or rulings were inconsistent with their nuclear ambitions. France and China never signed the 1963 Limited Test Ban Treaty—which has 126 parties including all other known nuclear weapons powers—and subsequently continued and began testing, respectively.[61] When the International Court of Justice ruled that France's atmospheric testing in the South Pacific might violate international law and issued Interim Measures (roughly analogous to an injunction), France rejected the Court's jurisdiction and proceeded with

55 N 38.

56 Non-Proliferation Treaty (n 38) art IV.1. The UN General Assembly has also declared that the peaceful development and use of nuclear energy to be a right of all states. UN General Assembly 32/50 (1977).

57 Convention on Nuclear Safety (opened for signatures 17 June 1994, entered into force 24 October 1996) 1963 UNTS 293.

58 ibid arts 10–19.

59 ibid arts 7–8.

60 ibid arts 5, 20–22.

61 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water (opened for signatures 5 August 1963, entered into force 10 October 1963) 480 UNTS 43.

atmospheric testing.[62] The 1996 Comprehensive Nuclear Test Ban Treaty has been ratified by 159 countries, but remains not in force due to the non-participation of eight 'select' countries, six of which have nuclear weapons (China, India, Israel, North Korea, Pakistan and the USA) and one of which appears to have ambitions for them (Iran).[63] The 1968 Non-Proliferation Treaty, with 189 parties, recognised the then-five nuclear weapon states, which are the permanent members of the UN Security Council.[64] All four countries that have developed nuclear weapons since then either never ratified the treaty or withdrew from it. Notably, such withdrawals are explicitly allowed if a state 'decides that extraordinary events, related to the subject matter of this Treaty, have jeopardized the supreme interests of its country'.[65] It also commits parties with nuclear weapons to 'pursue negotiations in good faith' on agreements for complete nuclear disarmament.[66] Those five parties have essentially ignored this.

This preference is also present, albeit to a lesser degree, in the case of nuclear power, whose international regulation is soft in form and limited in substance. Three Conventions are modest and have wide participation. The Convention on Nuclear Safety relies upon soft commitments to general principles of nuclear safety, 'reaffirm[s] that responsibility for nuclear safety rests with the State', and lacks both independent monitoring for compliance and an enforcement mechanism for non-compliance.[67] The Convention on Early Notification of a Nuclear Accident requires parties to notify neighbouring and the International Atomic Energy Agency (IAEA) Member States in the event of a potentially significant transboundary release of radiation, and partially standardises the information to be shared.[68] Parties to the Convention on Assistance in Case of a Nuclear Accident or Radiological Emergency are not obligated to provide or accept assistance but instead are obligated only to inform the IAEA of their available expertise and equipment.[69]

In contrast, the nuclear liability regimes—founded upon the Paris Convention for Western Europe and the Vienna Convention for other countries—could be potentially effective but are not adequately ratified.[70] Under these, liability is channelled to

62 Nuclear Tests cases: *Australia v France* (Interim Measures) (1973) ICJ Reports 99; *New Zealand v France* (Interim Measures) (1973) ICJ Reports 135.

63 Comprehensive Nuclear Test-Ban Treaty (opened for signatures 24 September 24 1996) 35 ILM 1439.

64 Non-Proliferation Treaty (n 38).

65 ibid art X.

66 ibid art VI. The International Court of Justice unanimously concluded that 'There exists an obligation to pursue in good faith and bring to a conclusion negotiations leading to nuclear disarmament in all its aspects under strict and effective international control.' *Legality of the Threat or Use of Nuclear Weapons*, Advisory Opinion, 8 July 1996 [1996] ICJ Rep 226.

67 Convention on Nuclear Safety (n 57). Quote is from Preamble, para iii.

68 Convention on Early Notification of a Nuclear Accident (opened for signatures 26 September 1986, entered into force 27 October 1986) 1439 UNTS 275.

69 Convention on Assistance in Case of a Nuclear Accident or Radiological Emergency (opened for signatures 26 September 1986, entered into force 26 February 1987) 1457 UNTS 133.

70 The cornerstones are the Paris Convention on Third Party Liability in the Field of Nuclear Energy (opened for signatures 29 July 1960, entered into force 1 April 1968) 956 UNTS 251 (Paris Convention); Vienna Convention on Civil Liability for Nuclear Damage (opened for signatures 21 May 1963, entered into force 12 November 1977) 1063 UNTS 265 (Vienna Convention). These are furthered by numerous supplements and protocols, some of which have minimal participation or are not yet in force. For a thorough overview, see Stephan Tromans, *Nuclear Law: The Law Applying to Nuclear Installations and Radioactive Substances in Its Historic Context* (2nd edn, Hart 2010) 166–82.

the operator of the nuclear power installation, who is solely and absolutely liable for transboundary damages.[71] Liability is limited in both time and amount. Operators are required to carry insurance up to a minimum that is stated in the treaties, but may be increased by the individual parties. If damages exceed the operator's liability, the state will provide public funds up to a second threshold. Under the Paris Convention regime, parties are collectively liable up to yet a higher amount. Legal actions are to be pursued in the courts of the party where the accident occurred. In theory, this liability regime is beneficial in a number of ways. Absolute liability allows the victims of a nuclear accident access to remedies without the burden to demonstrate fault. Furthermore, the courts need not define appropriate levels of care, which would be difficult given nuclear power's complexity. The responsibilities of the victims and the courts are further lessened by the channelling of liability to a single operator. Moreover, the nuclear industry has greater clarity and its operators are generally able to obtain insurance due to the channelling of liability to the operator and the limitations in amount and time. In reality, however, the effectiveness of the international nuclear accident liability regime is unclear. Less than half of the world's nuclear power capacity is located in a country that is a party to one of the two core treaties.[72] Furthermore, the limitations on the amount of liability are low, presently approximately 350 million euro, whereas a major nuclear accident could cost tens or hundreds of billions of euro.[73] The limitation of liability in time, generally at 10 years, also could be problematic, as some manifestations of radiation such as cancer may not occur within that time. Finally, the covered damage in the Western Europe regime is limited to people and property, not inclusive of damage to the environment or of lost economic activity. Notably, each of these shortcomings is addressed by existing conventions, protocols and supplementaries that are not yet in force or ratified only by few states with little nuclear power capacity.

From these details, we see that countries do have incentives to commit to general international safety principles and internationally coordinate information sharing and cooperation in the event of an accident. On the other hand, they lack adequate incentives for the international harmonisation of safety regulations and for strong liability measures. As a result, the regulation of nuclear power through public

71 Although demonstration of fault is not required, there are exceptions such as war, negligence of the victim, and grave natural disasters.

72 International Atomic Energy Agency, Nuclear Share of Electricity Generation in 2012 (2012) <http://www.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx> accessed 21 March 2014; Nuclear Energy Agency 'Paris Convention on Nuclear Third Party Liability: Latest Status of Ratifications or Accessions' <http://www.oecd-nea.org/law/paris-convention-ratification.html> accessed 21 March 2014; International Atomic Energy Agency, 'Vienna Convention on Civil Liability for Nuclear Damage' <http://www.iaea.org/Publications/Documents/Conventions/liability_status.pdf> accessed 21 March 2014.

73 Damages from the Chernobyl accident may have been on the order of hundreds of billions of euro. Chernobyl Forum, 'Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine' <http://www.iaea.org/Publications/Booklets/ss.html>, 33 Ludivine Pascucci-Cahen and Momal Patrick, 'Massive Radiological Releases Profoundly Differ from Controlled Releases' Institut de Radioprotection et de Sûreté Nucléaire (French Institute for Radiological Protection and Nuclear Safety) <http://www.irsn.fr/FR/Actualites_presse/Actualites/Documents/EN_Eurosafe-2012_Massive-releases-vs-controlled-releases_Cost_IRSN-Momal.pdf> accessed 15 March 2013.

international law is soft in form and limited in substance, and will most likely remain so. This implies that countries are reluctant to make strong binding commitments on a topic as close to national security as nuclear power, and that there will generally be trade-offs between proposed agreements' strength and their breadth of participation. Indeed, given that 'states continue to resist significant intrusions upon their sovereignty in the area of nuclear safety…modest and incremental inroads into autonomous national decisionmaking may be the most effective means of creating and maintaining state commitments'.[74]

The third observation about the international regulation of nuclear power is that it extends beyond centralised public international law. Instead, there are partially overlapping systems of regulation that differ in their geographic scales, breadths of participation, means and degrees of legalisation. These includes informal and formal norms; associations of experts and of institutional practitioners; self-, co-, meta- and private regulation and soft and binding policies. These occur at the national and international scales. Specifically, the most important international vehicle for the promotion of nuclear power safety is the standards of the IAEA.[75] These standards are binding only for projects that receive assistance from the IAEA, and such projects and their facilities are subject to inspection by the IAEA. However, the standards are influential and widely adopted voluntarily. These 'health and safety standards have been a significant contribution to controlling the risks of nuclear energy [and] have resulted in a high degree of harmonization'.[76] This can be attributed to the involvement of governments, intergovernmental organisations, non-governmental organisations and experts. Furthermore, states can (and sometimes do) voluntarily request from the IAEA inspection and advice for their nuclear facilities. In addition to the IAEA, the UN Scientific Committee on the Effects of Atomic Radiation assesses the effects of exposure to ionising radiation. The International Commission on Radiological Protection, a professional society, builds upon that work and issues recommendations as to how to reduce exposure. These recommendations are often influential in formulating IAEA standards.[77] The Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD), the private industry group World Association of Nuclear Operators, the US-initiated International Framework for Nuclear Energy Cooperation (until recently called the Global Nuclear Energy Partnership) and the World Institute for Nuclear Security reinforce the work of the IAEA in developing nuclear power and ensuring its safety. Their activities are further supported by the promulgation of norms, both informal and more explicit, such as those of the Nuclear Power Plant Exporters.[78]

Fourth, experts and expertise are essential in the regulation of nuclear power, not only because of nuclear power's technical character. A relatively small professional

74 Monica Washington, 'The Practice of Peer Review in the International Nuclear Safety Regime' (1997) 72 NYU L Rev 430, 440, 465.

75 Statute of the IAEA (n 38) arts III.6, XI, XII.

76 Patricia Birnie, Alan Boyle and Catherine Redgwell, *International Law and the Environment* (3rd edn, OUP 2009) 496.

77 ibid 44.

78 Nuclear Power Plant Exporters, 'Principles of Conduct' (2013) <http://nuclearprinciples.org/> accessed 5 May 2013.

cohort such as nuclear engineers and technicians are unlikely to readily accept detailed binding regulations developed by actors who are perceived to be outsiders. Moreover, the promulgation of, and adherence to, technical standards are not enough. Instead, as the experience in the USA after the 1979 Three Mile Island accident revealed, an appropriate culture among experts is necessary, something which can only be achieved with their cooperation.[79] In that case, an industry group—the Institute of Nuclear Power Operations—was formed in order to foster 'communitarian regulation,' which is 'well-defined industry morality that is backed by enough communal pressure to institutionalize responsibility among its members'.[80] Joseph Rees asserts that this organisation was successful because the accident was due to institutional failures, not to hardware or inadequate regulations, and because the nuclear power industry recognised itself as a community of shared fate due to its reputation 'commons'.[81] This is not to say that an activity as risky as nuclear power should be left to self-regulation, but instead to emphasise the need to integrate regulated experts as part of the regulatory process, particularly in technical cases.

Finally, the development of regulation, especially binding multilateral agreements, takes time. This is all the more the case in a dynamic technical field such as nuclear power, in which little is known during its infancy but more becomes known as research progresses. Furthermore, law is based on norms. Although some norms are general, within a new domain these must be refined gradually and emerge somewhat organically. The Convention on Nuclear Safety, arguably the most important multilateral agreement on the topic, was opened for signatures 52 years after the first nuclear reaction and 40 years after the first nuclear power installation. Even the rapid development of international environmental law from 1972 to 1992 was based on norms that initially developed decades earlier.[82]

5. LESSONS FOR CLIMATE ENGINEERING

We can now draw some lessons for the potential international regulation of climate engineering and its research. These will be based on several reasonable assumptions about the behaviour of states and about climate engineering. Regarding the former, I assume that states identify and pursue their self-interests, and will coordinate and cooperate among themselves when it is beneficial to them. In short, this is a

79 The US government's investigation of the accident, as well as other investigations, attributed the root cause to the institutional culture within the nuclear industry. John Kemeney and others, *The Need for Change, the Legacy of TMI: Report of the President's Commission on the Accident at Three Mile Island* (US Government Printing Office 1979); Hyman Rickover, 'An Assessment of the GPU Nuclear Corporation Organization and Senior Management and Its Competence to Operate TMI-l' (1983) <http://archives.dickinson.edu/sites/all/files/files_document/Rickover_Assessment.pdf> accessed 21 March 2014. '[I]f one all-important lesson attaches to the TMI accident, the accident examinations tell us, it mainly concerns…nuclear power's institutional arrangements.' Jospeh Rees, *Hostages of Each Other: The Transformation of Nuclear Safety Since Three Mile Island* (University of Chicago Press 1994) 12.

80 Rees, ibid 87.

81 ibid.

82 Eg Convention between the United States and Other Powers Providing for the Preservation and Protection of Fur Seals (opened for signatures 7 July 1911, entered into force 14 December 1911) 104 BFSP 175; *Trail Smelter Arbitration Tribunal (US v Canada)* (1939) 33 AJIL 182 & (1941) 35 AJIL 684; International Court of Justice, 'Corfu Channel Case (UK v. Albania)' (1949) ICJ Rep 4.

rationalist approach to international relations and to the resulting development of international law.[83] Further, because the climate significantly impacts a variety of state interests, climate change and climate engineering will be seen by states as matters of self-interest and even national security.[84] They will consequently act strongly in order to retain sovereignty in these areas and to maximise their net gains. Regarding climate engineering, I assume that it holds significant potential to reduce climate risks to humans and the environment, although it also poses risks of its own. Thus, climate engineering research should be pursued. Indeed, this has been the conclusion of a number of expert bodies,[85] and national governments are beginning to earmark funds for climate engineering research.[86] Finally, climate engineering should be appropriately internationally regulated in order to manage its transboundary risks. This is essentially the unanimous opinion of those who advocate for consideration of, and research into, climate engineering.[87]

I will first describe what is unlikely, and then what is likely, to occur. Note that one could make a wider range of observations, predictions, and recommendations regarding the international regulation of climate engineering. I limit myself here to those that can be inferred from the experience of nuclear power.

Climate engineering is not and will not be internationally prohibited, despite the desires of some.[88] In fact, its research is, and will continue to be, promoted, both internationally and domestically.[89] Moreover, climate engineering will not be the subject of a binding global agreement or protocol to an existing agreement, at least anytime in the near future, for several reasons. To the extent that climate change threatens state interests, climate engineering may offer an opportunity to reduce those threats. Those states with the capacity to research climate engineering or to deploy it—which will be the relatively powerful ones—as well as those states which are especially vulnerable to climate change will resist and not participate in proposed

83 See Andrew Guzman, *How International Law Works: A Rational Choice Theory* (OUP 2008).

84 See Daniel Moran (ed), *Climate Change and National Security: A Country-level Analysis* (Georgetown University Press 2011); Michael Link and others, 'Possible Implications of Climate Engineering for Peace and Security' (2013) 94 Bull Am Meteorol Soc ES13.

85 Innovation, Universities, Science and Skills Committee, *Engineering: Turning Ideas into Reality* (HC 2008-09, 50-I); Shepherd and others (n 6); Pamela Matson and others, *Advancing the Science of Climate Change* (National Academies Press 2010); Wilfried Rickels and others, *Large-Scale Intentional Interventions into the Climate System? Assessing the Climate Engineering Debate* <http://www.kiel-earth-institute.de/scoping-report-climate-engineering.html> accessed 14 November 2013; Jane Long and others (n 46); Nationalen Komitee für Global Change Forschung, der DFG Senatskommission für Ozeanographie, and der DFG Senatskommission Zukunftsaufgaben der Geowissenschaften, *Forschungsfragen einer gesellschaftlichen Herausforderung* <http://www.dfg.de/download/pdf/dfg_im_profil/reden_stellungnahmen/2012/stellungnahme_climate_engineering_120403.pdf> accessed 14 November 2013.

86 Engineering and Physical Sciences Research Council, *Climate Geoengineering Sandpit* <http://www.epsrc.ac.uk/funding/calls/2009/Pages/climategeoengsandpit.aspx> accessed 14 November 2013; Deutsche Forschungsgemeinschaft, *DFG-Schwerpunktprogramm 'Climate Engineering: Risks, Challenges, Opportunities?' (SPP 1689)* <http://www.dfg.de/Foerderung/info_wissenschaft/archiv/2012/info_wissenschaft_12_22/index.html> accessed 14 November 2013.

87 Eg the reports in (n 85) call for regulation.

88 Gerd Winter, 'Climate Engineering and International Law: Last Resort or the End of Humanity?' (2011) 20 RECIEL 277, 288.

89 Reynolds (n 12); n 86. Other countries and the EU have also publicly funded climate engineering research.

restrictive multilateral climate engineering agreements.[90] This is similar to the case of nuclear power, which internationally is regulated only weakly, as it provides material benefits to states—especially the powerful ones—who prefer to retain sovereignty over an issue so closely related to national security.[91] Furthermore, too much about climate engineering and its research remains uncertain: what it precisely may be, what forms it may take, what benefits and risks it may entail, how these effects and risks would be distributed, how reversible it would be, what states wish to get out of it, and what they wish to avoid. Any detailed or restrictive language would thus have unforeseeable consequences.[92] Uncertainty may be gradually reduced, of course. Recall that decades passed between the development of nuclear power and the passage and ratification of the Convention on Nuclear Safety, and climate engineering is at this moment arguably more uncertain than nuclear power was in the 1950s. The topic also remains too controversial. This is partially due to the lingering uncertainty, but also because it runs contrary both to the current 'dominant paradigm' in international climate debates of emissions reduction and adaptation, and to the underlying logic of many actors who advocate for action to reduce climate risks.[93] As a result, few of them have anything to gain—and much to lose—by proposing a new international law regime for climate engineering. Finally, after the flurry of multilateral environmental agreements of the 1990s, the international community has a generally low appetite for new treaties.

Instead, as with nuclear power, climate engineering research is likely to be internationally promoted and regulated gradually with a low degree of legalisation—at least initially—through a plurality of means and institutions.[94] As a first step, norms regarding, for example, transparency and the role of intellectual property must be developed.[95] This process will require significant time and a wide range of relevant actors, including experts such as climate engineering researchers.[96] While some of this discourse may occur within existing international legal forums such as the UNFCCC-COP

90 Of course, this could change if research indicates that climate engineering would increase risks more than decrease them and/or that many countries (or a few powerful ones) would be put at serious risk.

91 Text to (n 55–74).

92 Consider the often negative reaction against the statements from the Conference of Parties to the Convention on Biological Diversity (CBD-COP), eg Intergovernmental Oceanographic Commission Ad Hoc Consultative Group on Ocean Fertilization, 'Statement of the IOC Ad Hoc Consultative Group on Ocean Fertilization' in *Report on the IMO London Convention Scientific Group Meeting on Ocean Fertilization (IOC/INF-1247)* (UNESCO 2008).

93 The climate debates have been used as a vehicle for two other agendas, besides reducing risks to humans and the environment. The 'greener' environmental groups seek to reduce the overall footprint of humanity on the natural world. Others see action against climate risks as a means to international retributive justice. Climate engineering would not further either of these two agendas. See Gareth Davies, 'The Psychological Costs of Geoengineering: Why It May Be Hard to Accept Even If it Works' in Wil Burns and Andrew Strauss (eds), *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks* (CUP 2012) 71–77.

94 Consider the roles of and interactions among various institutions in the case of nuclear power and its safety. Text to (n 75–78).

95 This is already occurring. Text to (n 106–108).

96 This is not to imply that the roles of experts and expertise in law are simple. Indeed, there is a large literature on their sometimes problematic relationship. For differing perspectives, see Sheila Jasanoff, *Science at the Bar: Law, Science, and Technology in America* (Harvard University Press 1997); Roger Pielke, Jr, *The Honest Broker: Making Sense of Science in Policy and Politics* (CUP 2007).

and the Intergovernmental Panel on Climate Change, other sites with less prior commitment to the 'dominant paradigm' of emissions reduction and adaption, and greater opportunity for candour will also be necessary. After some time, these norms will lay the foundation for soft policy among non-legal institutions, such as national and international scientific societies. Once significant climate engineering field testing begins, it may then be in States' interest to coordinate their climate engineering activities, formally and informally, to establish and clarify standards, minimise interference among projects, distribute costs, build capacity, combat free-riding in research efforts and prevent misuse. This would be not unlike the IAEA's three pillars: safety and security, fostering technology and preventing proliferation.[97] A key question at this juncture—if not sooner—will be whether to place a moratorium on large-scale field research and deployment, and if so, by whom and how.

Once norms and soft policies are in place, and once field activities have reached a scale that they may pose transboundary risks, there will then be a larger role for the development of international law, broadly defined. Considering the low level of legalisation of existing international law governing nuclear power, resulting documents concerning climate engineering will likely be—even then—non-binding guidelines and relatively soft multilateral agreements.[98] These will be dominated by procedural duties such as prior assessment, notification, monitoring, information sharing, public access to information, consultation and coordination of responses to negative events. Meanwhile, states could at that time develop, monitor and enforce more detailed domestic regulations. Liability for damages will be controversial. Generally speaking, a liability regime similar to that for nuclear accidents may be beneficial, at least in theory.[99] This could involve strict, limited liability with channelling to the state instead of the 'operator' (due to researchers' relatively smaller budgets) and with pooling of liability among those states active in research (due to the very large potential damages and to the public good character of climate engineering research). However, proving causation in a climate liability claim would be very challenging.

When and if some states gain the capability for the deployment of large-scale climate engineering methods, they will wish to limit such ability to themselves. Although this might give a first impression of brute power aggrandisement, it may be beneficial to have a smaller number of countries that can intervene in the global climate.[100] This would minimise conflicts among States and interference among climate engineering projects, assuming that decisions to affect the global climate are taken in a

97 The functions of the Agency were originally provided in Statute of the IAEA (n 38) art III.A but then expanded, particularly through the Non-Proliferation Treaty (n 38) and the Convention on Nuclear Safety (n 57).

98 Some may argue that the 2010 decision on climate engineering by the CBD-COP runs counter to my analysis. However, it uses strongly qualified language and is non-binding. Report of the Tenth Meeting of the Conference of Parties to the Convention on Biological Diversity' UN Doc UNEP/CBD/COP/27 (2010) X/33/8(w). See also Secretariat of the Convention on Biological Diversity, *Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters* (CBD Technical Series No 66, Secretariat of the Convention on Biological Diversity 2012), 6, which calls the decision 'a non-binding normative framework'.

99 Text to (n 70–73).

100 Consider the analogy with nuclear weapons. A world in which only a few countries have nuclear weapons is more stable and less likely to experience nuclear warfare than one in which most countries have them.

transparent and inclusive manner. Thus, a non-proliferation agreement—binding or possibly less formal—could be roughly analogous to the Nuclear Non-Proliferation Treaty.[101] Under this, those parties with climate engineering capabilities would pledge to share knowledge with non-capable parties and to include them in research activities, while not sharing knowledge and research activities with non-participating states. In turn, all parties would agree to limit climate engineering capabilities to a small number of States and to abide by certain research standards.

In this regulation of large-scale climate engineering field experiments and deployment, one or more institutions similar to the IAEA and the others involved in overseeing nuclear power could play several important facilitative roles.[102] Such institutions could further research norms and guidelines by, for example, translating them into detailed best practices and assisting with their implementation among researches and through national legislation. They could also help coordinate climate engineering activities, minimising the conflicts among field tests. This could include fairly distributing costs and fostering research capacity, particularly in developing countries. Moreover, an international institution could provide a site where a moratorium on large-scale field experiments and deployment could be developed and modified as appropriate. Finally, institutions could promulgate and help implement multilateral agreements regarding the above-listed procedural duties, liability and non-proliferation. For example, they could provide forums for information sharing and access, adjudicate liability claims and verify non-proliferation.

Although the rules regarding when climate engineering deployment would be permitted is already a matter of much interest, it may be wise to delay formal discussions on this. Such debates could unnecessarily increase international tensions and cloud understandings of climate engineering, while details are still emerging regarding climate change risks, states' ability to reduce these risks through emissions reductions and adaptation, the nature and potential of climate engineering, and what society desires out of climate engineering. Although one could imagine climate engineering becoming a source of polarised debate and tension among countries, this is not as probable as some authors suggest.[103] In fact, current models indicate that countries may more strongly agree on whether and to what degree climate engineering should be deployed than how much they may disagree over the details.[104] Furthermore, if a final lesson from nuclear *weapons* may be drawn, international norms may develop which can prevent misuse in cases where explicit multilateral agreements are impossible to reach—even in the *realpolitik* world of national security.[105]

101 Non-Proliferation Treaty (n 38).

102 Banerjee (n 26) also suggests looking at the IAEA as an example.

103 Eg David Victor, 'On the Regulation of Geoengineering' (2008) 24 O Rev Env Pol'y 322.

104 See Ricke, Moreno-Cruz and Caldeira (n 10).

105 Nuclear weapons have never been used outside of the arguably exceptional case of World War II. There is a strong international norm against the first-strike use of nuclear weapons, especially against a non-nuclear state. This has been maintained for decades despite the fact that in several instances it would have been advantageous for states to use them. However, it is improbable that the nuclear weapon states would commit to such a norm in a binding treaty or UN Security Council resolution. See Thomas Schelling, 'An Astonishing Sixty Years: The Legacy of Hiroshima', Nobel Prize Lecture, 8 December 2005, available at <http://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/2005/schelling-lecture.html> accessed 11 October 2013.

6. CONCLUSION

The initial steps on the trajectory described in the last section are already occurring. In recent years, at least three different ad hoc expert bodies have produced norms to guide climate engineering research, with significant agreement among their products.[106] International institutions are cautiously dipping their toes into the potentially treacherous waters of examining climate engineering.[107] Leading researchers are now discussing prohibitions on climate engineering patents and a moratorium on large-scale field research and deployment.[108] This is not to say that concerned participants in the climate engineering regulation discourse should become complacent. Quite the contrary, all voices, ranging from active practitioners to strident opponents, must be fully engaged in order to better shape one of the most challenging international regulatory developments of this era. This engagement will be more productive if the participants are aware of the range of likely rational behaviour of sovereign states with diverse interests, capabilities and levels of power, as evidenced by the instructive case of nuclear power.

106 MacCracken and others (n 46); Jane Long and others (n 46); Rayner and others (n 46). See also Solar Radiation Management Governance Initiative, 'Solar radiation management: the governance of research' <http://www.srmgi.org/report/> accessed 19 April 2013.

107 Eg Stocker and others (n 2).

108 Anne Mulkern, 'Researcher: Ban Patents on Geoengineering Technology' (*ClimateWire*, 2012) available at <http://www.scientificamerican.com/article.cfm?id=researcher-ban-patents-on-geoengineering-technology> accessed 10 May 2012; Parson and Keith (n 21).

Climate Engineering Field Research: The Favorable Setting of International Environmental Law

Jesse Reynolds*

Abstract

As forecasts for climate change and its impacts have become more dire, climate engineering proposals have come under increasing consideration and are presently moving toward field trials. This article examines the relevant international environmental law, distinguishing between climate engineering research and deployment. It also emphasizes the climate change context of these proposals and the enabling function of law. Extant international environmental law generally favors such field tests, in large part because, even though field trials may present uncertain risks to humans and the environment, climate engineering may reduce the greater risks of climate change. Notably, this favorable legal setting is present in those multilateral environmental agreements whose subject matter is closest to climate engineering. This favorable legal setting is also, in part, due to several relevant multilateral environmental agreements that encourage scientific research and technological development, along with the fact that climate engineering research is consistent with principles of international environmental law. Existing international law, however, imposes some procedural duties on States who are responsible for climate engineering field research as well as a handful of particular prohibitions and constraints.

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I. Introduction

Efforts thus far to reduce the risks from anthropogenic climate change have been disappointing. In response, some scientists are investigating intentional, large-scale interventions in global chemical, physical, and biological systems in order to reduce climate risks.[1] These proposed "climate engineering" or "geoengineering" methods are controversial, in part, because some of them pose risks of their own to humans and the environment.[2] International environmental law plays an important role in any discussion of climate engineering because some

1. *See generally* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS (June 7, 2013) [hereinafter IPCC, PHYSICAL SCIENCE], *available at* http://www.climatechange2013.org/report/ (examining the potential of climate engineering as potential additional responses to climate change).

2. *See id.* at § TS.5.6 (discussing the risks associated with climate engineering and carbon dioxide reduction).

climate engineering techniques may cause trans-boundary damage or damage in areas beyond state jurisdiction.[3]

This article examines how existing international environmental law may regulate and influence field testing of climate engineering. In its examination, this article (1) distinguishes between climate engineering field research and deployment, focusing on the former due to its urgency; (2) considers climate engineering proposals in the context of climate change; and (3) emphasizes the enabling function of law.

Some multilateral environmental agreements (MEAs) suggest that States seeking to protect the environment should balance the risks associated with climate engineering field tests with the reduction of climate change risks. Typically, this balance favors climate engineering field research. Although none of the MEAs address climate engineering directly, it is notable that those whose content is the closest to addressing climate engineering are among those that encourage its research. A second reason for this favorable legal setting is that many MEAs call upon States to engage in scientific research and technological development. Finally, climate engineering research is consistent with principles of international environmental law such as precaution, polluter pays, and common but differentiated responsibilities. Concurrently, existing laws impose a number of procedural duties, and they constrain or prohibit specific actions.

Part II of this article describes climate change and climate engineering along with some of the associated risks. Part III frames the discussion by considering several relevant legal topics. The subsequent three Parts examine binding MEAs, nonbinding MEAs, and customary international law, respectively. In the final Part, I conclude that the current international framework is favorable to future climate engineering research, although, there are a handful of unresolved issues.

II. Climate Change and Climate Engineering

Climate change is among the greatest challenges facing society today.[4] Humans are increasing the atmospheric concentrations of so-called greenhouse gases—especially carbon dioxide—which let light in but

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3. *See id.* (noting that in order for climate engineering methods to be effective, they need to be implemented on a large scale in order for the techniques to be effective).

4. *See* Ban Ki-moon, Sec'y-Gen., United Nations, Remarks at the Thirty-ninth Plenary Assembly of the World Federation of United Nations Associations (Aug. 10, 2009), *available at* http://www.un.org/apps/news/infocus/sgspeeches/statments_full.asp?statID=555 ("[Climate change] is, simply, the greatest collective challenge we face as a human family.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

obstruct the escape of heat.[5] Although most of these gases occur naturally, activities such as fossil fuel combustion and land use changes result in emission rates that are higher than their natural removal rate, leading to their accumulation in the Earth's atmosphere.[6] As the forecasts for climate change and its effects have become direr, a wider spectrum of responses has been considered. Initially, international responses focused on the abatement of greenhouse gas emissions.[7] The leading vehicle for global cooperative abatement, the Kyoto Protocol to the United Nations Framework Convention on Climate Change, however, may not have actually reduced emissions.[8] There are several additional reasons for pessimism looking forward. First, fossil fuel combustion is essential to economic activity, and its reduction carries large costs.[9] Moreover, most current emissions are, and most future emissions will be, produced by developing countries that understandably insist on economic development and improvements in living conditions.[10] Second, because the negative effects of greenhouse gases will occur decades after they are emitted and independently from their location, their abatement presents an enormous global and intergenerational collective action problem.[11] In any international abatement agreement, each country is asked to undertake costly actions to prevent damage that will occur mostly in distant locations and in the future.[12] Such steps are politically unpopular and it is tempting to free-ride

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5. *See* IPCC, PHYSICAL SCIENCE, *supra* note 1, § 1.2.2 (describing the effects created by certain gases and stating that "[h]umans enhance the greenhouse effect directly by emitting greenhouse gases").

6. *See id.* § TS.3.2 ("Human activity leads to change in the atmosphere composition either directly (via emissions of gases or particles) or indirectly (via atmospheric chemistry).").

7. *See* E. Lisa F. Schipper, *Conceptual History of Adaptation in the UNFCCC Process*, 15 REV. EUR. COMMUNITY & INT'L ENVTL. L. 82, 82–83 (describing the focus on emission reductions in early international climate negotiations).

8. *See* Quirin Schiermeier, *Hot Air*, 491 NATURE 656, 656 (2012) (stating that most Kyoto targets were met only due to economic downturns in Eastern Europe in the 1990s and worldwide in the late 2000s, and were more than offset by emission increases in countries without commitments under the Kyoto Protocol).

9. *See* WILLIAM D. NORDHAUS, A QUESTION OF BALANCE: WEIGHING THE OPTIONS ON GLOBAL WARMING POLICIES 82 (2008) (estimating that both climate damage and emissions abatement costs are on the order of trillions to tens of trillions of dollars).

10. *See* INTERNATIONAL ENERGY AGENCY, WORLD ENERGY OUTLOOK 2013 § 2 (Nov. 12, 2013) (looking at global trends in energy usage through 2035).

11. *See* IPCC, PHYSICAL SCIENCE, *supra* note 1, § 12.5.2 (describing how the Earth's surface temperatures lag behind changes in greenhouse gas concentrations).

12. *See* David G. Victor, *On the Regulation of Geoengineering*, 24 OXFORD REV. ECON. POL'Y 322, 324 (2008) ("With today's technologies, achieving a deep cut in emissions will require costly investment for uncertain benefits that accrue mainly in the distant future—attributes that tend not to be rewarding for politicians."); *see also*

or to defect from these agreements.[13] Third, because excess carbon dioxide naturally leaves the atmosphere slowly, emission reductions would merely delay a given amount of climate change.[14] Therefore, avoiding dangerous climate change requires radical changes in energy systems and net negative emissions.[15]

The second international response to the problem of climate change has been adaptation to the changing climate conditions.[16] Adaptation was initially decried as "a kind of laziness, an arrogant faith in our ability to react in time to save our skin," but is now considered another legitimate response.[17] The capacity for adaptation is also limited.[18] It is more urgent in

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NORDHAUS, *supra* note 9, at 4–6 (describing the impact that climate change will have across the globe).

13. *See Twelve Years of the Public's Top Priorities*, THE PEW RESEARCH CENTER FOR THE PEOPLE AND THE PRESS (Jan. 24, 2013), http://www.people-press.org/interactives/top-priorities/ (demonstrating that the issue of global warning has been at or near the bottom of United States public policy priorities since its inclusion in 2007) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

14. *See* IPCC, PHYSICAL SCIENCE, *supra* note 1, § 12.5.2 ("[P]ast emissions commit us to persistent warming for hundreds of years . . . .").

15. *See* Ken Caldeira, *Climate Sensitivity Uncertainty and the Need for Energy Without CO_2 Emission*, 299 SCIENCE 2052, 2053 (2003) ("To achieve stabilization at a 2°C warming, we would need to install ~900 ± 500 [megawatts] of carbon emissions-free power generating capacity each day over the next 50 years. This is roughly the equivalent of a large carbon emissions-free power plant becoming functional somewhere in the world every day."); IPCC, PHYSICAL SCIENCE, *supra* note 1, § SPM E.1, 12.3.1.3 (describing how the only Representative Concentration Pathway scenario considered by the IPCC under which global surface temperature change is likely remain below two degrees Celsius—an internationally agreed-upon target—through the end of the century is RCP2.6, which assumes net negative emissions).

16. *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2014: IMPACTS, ADAPTATION AND VULNERABILITY, FINAL DRAFTS (ACCEPTED) § 14.1 (Oct. 28, 2013) [hereinafter IPCC, IMPACTS], *available at* http://ipcc-wg2.gov/AR5/report/final-drafts/ ("Human and natural systems have a capacity to cope with adverse circumstances, but with continuing climate change, adaptation will be needed to maintain this capacity."); *Adaptation Overview*, ENVTL. PROT. AGENCY, http://www.epa.gov/climatechange/impacts-adaptation/adapt-overview.html (last visited Jan. 13, 2014) ("'Adaptation' refers to efforts by society or ecosystems to prepare for or adjust to future climate change.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

17. *See* AL GORE, EARTH IN THE BALANCE: ECOLOGY AND THE HUMAN SPIRIT 240 (1993) ("Believing that we can adapt to just about anything is ultimately a kind of laziness, an arrogant faith in our ability to react in time to save our skin."); Schipper, *supra* note 7, at 91 ("Since 2002, a complementary approach between adaptation and mitigation has gained support, with the acknowledgement that adaptation and mitigation are not alternatives . . . .").

18. *See* IPCC, IMPACTS, *supra* note 16, § 16.4 (noting that, beyond a certain point, adaptive efforts fail to provide "an acceptable level of security from risks").

developing countries, which are more vulnerable to climate change due to their geographies and economies.[19]

Industrialized countries are expected to finance adaption in poorer countries, as industrialized countries have historically dominated cumulative emissions.[20] Climate adaptation, however, can be difficult to distinguish from traditional development projects.[21] Industrialized countries can simply reclassify traditional development aid, and developing countries can simply reclassify traditional development projects as climate adaptation financing.[22] Adaptation financing appears to be inadequate, although it is increasing.[23]

Climate engineering is presently emerging as a third potential set of responses to climate change.[24] There are numerous proposed climate engineering methods which vary widely in their means, goals, speeds, costs, risks, capacities, and potential effectiveness.[25] They are divided into two distinct categories. The first is carbon dioxide removal (CDR), increasingly called "negative emissions technologies," in which intentional, large-scale

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19. *See id.* at § SPM (citing particular vulnerabilities in developing countries to flooding, economic losses from disasters, negative human health effects, displacement, and increased poverty).

20. *See, e.g.*, United Nations Framework Convention on Climate Change art. 1, para. 1, *opened for signature* May 9, 1992, S. Treaty Doc. No. 102-38, 1771 U.N.T.S. 171 [hereinafter UNFCCC] (discussing the responsibilities of developed countries under the UNFCCC).

21. *See* IPCC, IMPACTS, *supra* note 16, § 14.5 ("[Experts] have found it difficult to clearly define and identify precisely what constitutes adaptation, how to track its implementation and effectiveness, and how to distinguish it from effective development.").

22. *See, e.g.*, BLOOMBERG NEW ENERGY FINANCE, HAVE DEVELOPED NATIONS BROKEN THEIR PROMISE ON $30BN 'FAST-START' FINANCE? (Victoria Cuming ed., 2011), *available at* http://about.bnef.com/white-papers/have-developed-nations-broken-their-promise-on-30bn-fast-start-finance/ (observing that "only a small proportion of the promised funds [from developed countries] are 'new and additional,' with the rest diverted from other aid budgets") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

23. *See* IPCC, IMPACTS, *supra* note 16, § 17 ("Global adaptation cost estimates are substantially greater than current adaptation funding and investment, particularly in developing countries, suggesting a funding gap and a growing adaptation deficit.").

24. *See* Christopher W. Belter & Dian J. Seidel, *A Bibliometric Analysis of Climate Engineering Research*, 4 WILEY INTERDISC. REV. CLIMATE CHANGE 417, 417 (2013) ("The past five years have seen a dramatic increase in the number of media and scientific publications on the topic of climate engineering, or geoengineering, and some scientists are increasingly calling for more research on climate engineering as a possible supplement to climate change mitigation and adaptation strategies.").

25. *See generally* JOHN SHEPHERD ET AL., THE ROYAL SOCIETY, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE AND UNCERTAINTY (2009) (summarizing approaches to climate engineering); GEOENGINEERING RESPONSES TO CLIMATE CHANGE: SELECTED ENTRIES FROM THE ENCYCLOPEDIA OF SUSTAINABILITY SCIENCE AND TECHNOLOGY (Tim Lenton & Naomi Vaughan eds., 2013) (discussing various climate engineering methods).

interventions in earth systems would sequester the most important greenhouse gases.[26] Speaking generally and relatively, while these less controversial and risky technologies would address climate change close to its cause, they would be slow and expensive.[27] Indeed, most risks of CDR are local and of a character consistent with typical industrial activities, although the environmental impacts could be quite significant if CDR is scaled-up.[28] A significant exception to these general CDR characteristics is ocean fertilization.[29] This process would accelerate the natural biological carbon "pump," in which marine phytoplankton indirectly incorporate atmospheric carbon dioxide into their bodies as they grow.[30] The phytoplankton then sequester that carbon in the deeper ocean as they die and sink.[31] Some scientists believe that adding a locally limiting nutrient (usually iron) to an area of the ocean would stimulate the growth of phytoplankton and lead to significant carbon sequestration.[32] This method, however, poses risks to marine ecosystems.[33] To date, over a dozen ocean fertilization field trials have produced mixed results.[34]

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26. *See* IPCC, PHYSICAL SCIENCE, *supra* note 1, Annex III (defining CDR as "a set of techniques that aim to remove *CO_2* directly from the *atmosphere* by either (1) increasing natural *sinks* for carbon or (2) using chemical engineering to remove the CO_2, with the intent of reducing the atmospheric CO_2 concentration"(emphasis original)).

27. *See* THE ROYAL SOCIETY, *supra* note 25, at 21 (noting that CDR methods are technically possible and would have environmental impacts commensurate with their scale, carry high costs, and operate slowly).

28. *See* IPCC, PHYSICAL SCIENCE, *supra* note 1, § 6.5.1 (describing "direct air capture of CO_2 using industrial methods"); *id.* ("[I]t is likely that CDR would have to be deployed at large-scale for at least one century to be able to significantly reduce atmospheric CO_2.").

29. *See id.* § 6.5.2.2 (noting that ocean fertilization seeks to increase the rate of transfer in the carbon cycle).

30. *See* THE ROYAL SOCIETY, *supra* note 25, at 16 ("Carbon dioxide is fixed from surface waters by photosynthesisers—mostly, microscopic plants (algae). Some of the carbon they take up sinks below the surface waters in the form of organic matter . . . .").

31. *See id.* at 17 ("The combined effect of photosynthesis in the surface followed by respiration deeper in the water column is to remove CO_2 from the surface and re-release it at depth. This 'biological pump' exerts an important control on the CO_2 concentration of surface water, which in turn strongly influences the concentration in the atmosphere.").

32. *See id.* ("Methods [of fertilization] have been proposed to add otherwise limiting nutrients to the surface waters, and so promote algal growth, and enhance the biological pump.").

33. *See* Phillip Williamson et al., *Ocean Fertilization for Geoengineering: A Review of Effectiveness, Environmental Impacts and Emerging Governance*, 90 PROCESS SAFETY AND ENVTL. PROT. 475, § 5 (2012) ("A range of unintended and mostly undesireable impacts of large-scale fertilization . . . include production of climate-relevant gases . . . ; effects on productivity; . . . and effects on seafloor ecosystem[s].").

34. *See* SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, CONVENTION ON BIOLOGICAL DIVERSITY, TECHNICAL SERIES NO. 45: SCIENTIFIC SYNTHESIS OF THE IMPACTS OF OCEAN FERTILIZATION ON MARINE BIODIVERSITY 52 tbl.1 (2009) (summarizing field trials).

The other category of climate engineering is solar radiation management (SRM), which attempts to increase the portion of the incoming sunlight that is reflected, counterbalancing the warming component of climate change.[35] In general, and relative to CDR, SRM would be fast and inexpensive, but would address only a symptom of climate change, create substantial risks, and is controversial.[36] Three proposed methods stand out as potentially effective, but are potentially risky. First, under stratospheric aerosol injection (SAI), small particles would be introduced into the upper atmosphere, mimicking the cooling effect that is observed after large volcanic eruptions or—at lower atmospheric altitudes—in cities with air pollution.[37] Under the second method, marine cloud brightening (MCB), ocean water would be sprayed into the air.[38] The salt dust, which would remain after the droplets evaporate, would act as cloud condensation nuclei, in turn causing clouds to be more reflective.[39] The third method would place objects, such as mirrors or dust, in space.[40] These proposed SRM methods pose uncertain risks to the environment and humans. For example, SRM would unequally counteract the temperature and precipitation perturbations due to climate change.[41] The result could be reduced precipitation in some areas.[42] Furthermore, sunlight reaching the ground would be more diffuse while carbon dioxide concentrations remain elevated, increasing plant primary productivity and altering ecosystems.[43] The leading candidate for stratospheric injection, sulfur dioxide, may

35. *See* IPCC, PHYSICAL SCIENCE, *supra* note 1, Annex III (defining SRM as "the intentional modification of the Earth's shortwave radiative budget with the aim to reduce *climate change* according to a given *metric*" (emphasis original)).

36. *See id.* § 7.7 (discussing the consequences of SRM techniques).

37. *See* THE ROYAL SOCIETY, *supra* note 25, at 29 ("Simulating the effect of large volcanic eruptions on global climate has been the subject of proposals for climate geoengineering for some time . . . . These proposals aim to artificially increase suphate aerosols in the stratosphere . . . thereby reducing the incoming solar radiation.").

38. *See id.* at 27 (describing the process by which the salt from ocean water would be used to increase the number of cloud-condensation nuclei.).

39. *See id.* ("It is readily demonstrated that many small cloud micro droplets scatter and so reflect more of the incident light than a smaller quantity of larger droplets of the same total mass since the surface area of the small droplets is greater.").

40. *See id.* at 32 ("Space-based methods propose to reduce the amount of solar energy reaching Earth by positioning sun-shields in space to reflect or deflect the solar radiation.").

41. *See* Simone Tilmes et al., *The Hydrological Impact of Geoengineering in the Geoengineering Model Intercomparison Project (GeoMIP)*, 118 J. GEOPHYSICAL RESEARCH: ATMOSPHERES 11036, 11053 (2013) (describing the uneven effects of SRM on temperature and precipitation).

42. *See id.* ("[T]he hydrological cycle would be perceptibly weakened by SRM . . . .").

43. *See* J. Pongratz et al., *Crop Yields in a Geoengineered Climate*, 2 NATURE CLIMATIC CHANGE 101, 101 (2012) ("We find that in our models solar-radiation geoengineering in a high-CO_2 climate generally causes crop yeields to increase, largely because temperature stresses are deiminshed . . . .").

damage the ozone layer.[44] Finally, if large-scale SRM were to stop suddenly, then climate change—most of which would have been suppressed by SRM—would accelerate, potentially causing more damage than if it had occurred over decades.[45] SRM techniques, however, are attractive due to their ability to strongly and rapidly affect a large area at little cost.[46] Because of SRM's attractiveness, risks, and potential low barriers to entry, world leaders would need to address decision-making, unilateralism, control, and conflict.[47]

There are some risks that would be prevalent in both climate engineering categories. For example, many commentators express concern that discussion of or research into climate engineering would reduce incentives and political willpower toward the preferred paths of emissions reductions and adaptation.[48] Others cite the potential development of vested interests and technological momentum, which could influence future policy.[49]

Although most of the public and academic climate engineering discourse has focused on possible deployment, field research is more urgent.[50] Logically—and hopefully—testing will occur before any deployment. Indeed, climate engineering research budgets are increasing and some projects now include field work.[51] Early SRM field experiments

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44. *See* P. Heckendorn et al., *The Impact of Geoengineering Aerosols on Stratospheric Temperature and Ozone*, 4 ENVTL. RESEARCH LETTERS 1, 11 (2009) (linking proposed sulfur stratospheric aerosol injection with likely ozone depletion).

45. *See* IPCC, PHYSICAL SCIENCE, *supra* note 1, at 7-5 ("Additionally, scaling SRM to substantial levels would carry the risk that if the SRM were terminated for any reason, there is *high confidence* that surface temperatures would increase rapidly . . . which would stress systems sensitive to the rate of climate change.").

46. *See* THE ROYAL SOCIETY, *supra* note 25, at 34 ("It is likely that once a SRM method is implemented the climate system woud respond quite quickly with surface temperatures . . . .").

47. *See, e.g.*, David G. Victor, *On the Regulation of Geoengineering*, 24 OXFORD REV. ECON. POL'Y 322, 333 (2008) ("Growing attention to geoengineering will create pressure for regulation.").

48. *See* Albert Lin, *Does Geoengineering Present a Moral Hazard?*, 40 ECOLOGY L.Q. 673, 674 (2013) ("Among the leading reasons for the geoengineering taboo was the worry that geoengineering endeavors would undermine mainstream efforts to combat climate change.").

49. *See*, *e.g.*, Dale Jamieson, *Ethics and Intentional Climate Change*, 33 CLIMATIC CHANGE 323, 333 (1996) ("[R]esearching a technology risks inappropriately developing it . . . . A research program often creates a community of researchers that functions as an interest group promoting the development of the technology that they are investigating.").

50. *See* Jesse Reynolds, *The Regulation of Climate Engineering*, 3 L. INNOVATION & TECH. 113, 126 (2011) (arguing that climate change field research should generally be considered distinct from deployment and that regulation of the former is more urgent).

51. *See, e.g.*, *Research to Evaluate Climate Engineering: Risks, Challenges, and Opportunities?*, DEUTSCHE FORSCHUNGSGEMEINSCHAFT (May 27, 2013, 16:39),

are examining natural, analogous phenomena and are also testing equipment.[52] At some point in the progression of this research, scientists will desire to study the effectiveness and side effects of various SRM methods.[53] It may be advantageous for scientists to begin SRM field tests relatively soon, because field tests with longer durations would require less forceful climatic interventions in order to detect a significant signal among the noise of weather.[54] If the experiments are significant enough to alter the climate, then there is the potential for them to pose some associated risk.[55] Not all climate engineering field research, however, will pose environmental risks.[56] This paper specifically addresses field tests of the riskier methods, such as ocean fertilization, SAI, and MCB, which are designed to sequester a significant amount of carbon or to alter a regional climate significantly.

III. Legal Aspects

Before moving into this paper's core, which examines existing international environmental law, several germane legal matters must be

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http://www.spp-climate-engineering.de/news-single/items/287.html (announcing a new program from the German Science Foundation that aims "to reduce the large uncertainties in our current understanding of the impact of [climate engineering] on the planet") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); Daniel Cressey, *Cancelled Project Spurs Debate over Geoengineering Patents*, 485 NATURE 429 (2012) (describing a planned field test of stratospheric injection equipment).

52. *See, e.g.*, Yu. A. Izrael et al., *Field Studies of a Geo-engineering Method of Maintaining a Modern Climate with Aerosol Particles*, 34 RUSSIAN METEOROLOGY & HYDROLOGY 635 (2009) (reporting the results of field experiments "studying the solar radiation transmission in the visible wavelength range with model aerosol media formed in the middle troposphere with the help of high-efficient standard aerosol generators aboard the helicopter"); Henry Fountain, *Trial Balloon: A Tiny Geoengineering Experiment* GREEN: ENERGY, THE ENV'T AND THE BOTTOM LINE (Jul. 17, 2012, 2:17 PM), http://green.blogs.nytimes.com/2012/07/17/trial-balloon-a-tiny-geoengineering-experiment/ (reporting on plans for a possible field trial in the United States) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

53. *See* David Keith et al., *Research on Global Sun Block Needed Now*, 463 NATURE 426, 427 (2010) (arguing for field studies of SRM climate engineering).

54. *See* Douglas G. MacMynowski et al., *Can We Test Geoengineering?*, 4 ENERGY ENVTL. SCI. 5044, 5044 (2011) (quantifying "the trade-offs between duration and intensity of the test and it's [sic] ability to make quantitative measurements of the climate's response to SRM forcing").

55. *See* Alan Robock et al., *Studying Geoengineering with Natural and Anthropogenic Analogs*, 121 CLIMATIC CHANGE 445, 446 (2013) (noting that "even small-scale experiments outside a laboratory environment could carry some risk").

56. *See* Edward A. Parson & David W. Keith, *End the Deadlock on Governance of Geoengineering Research*, 339 SCIENCE 1278, 1279 ("[M]uch promising process research has trivial environmental impact, smaller than common commercial activities . . . .").

briefly addressed. First, when a powerful new technology—particularly if it poses risks to humans and the environment—is proposed or introduced, it is important to determine the ways in which existing law prohibits, permits, or encourages its use.[57] There are no MEAs and almost no international law, broadly defined, that directly address climate engineering.[58] Several MEAs and aspects of customary international law, however, are important both in a narrow sense of their specific application, and more generally—and probably more importantly—when discussing the legal environment into which any climate engineering research or techniques would be introduced.[59] Using a framework for regulation put forth by Roger Brownsword,[60] I conclude that generally, extant law *channels* positively, in that it encourages climate engineering research, and that it has a positive regulatory *tilt*, in that gaps or ambiguities in the law will more often be resolved as permissive.[61] It is in this sense that I assert that international environmental law is favorable to climate engineering research.

The second matter is that, throughout these discussions, there is often tension between the potential for climate engineering research to reduce climate risks to humans and the environment, and its own potential to cause harm.[62] For shorthand, I refer to this as the "climate change/climate engineering tension." Although balancing such potential benefits and risks is generally not a means of interpreting international law, in the case of climate engineering, it is the logical way to proceed.[63] I argue below that existing international environmental law is best interpreted as being

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57. *See* Roger Brownsword & Han Somsen, *Law, Innovation and Technology: Before We Fast Forward, A Forum for Debate*, 1 L. INNOVATION & TECH. 1 (2009) (describing the importance of the regulatory environment for a new technology).

58. *See* Karen N. Scott, *International Law in the Anthropocene: Responding to the Geoengineering Challenge*, 34 MICH. J. INT'L L. 309, 330 (2013) ("With the exception of reforestation and afforestation and ocean fertilization for scientific research purposes there are few legal instruments explicitly applicable to geoengineering.").

59. *See infra* Parts IV–VI (discussing binding and nonbinding MEAs, as well as customary international law).

60. ROGER BROWNSWORD, RIGHTS, REGULATION, AND THE TECHNOLOGICAL REVOLUTION (2008).

61. *See id.* at 19–21 (presenting an analytical framework to examine regulations and describe their relationship with policy goals, wherein a regulatory "tilt" is a default position of regulators that can be interpreted despite ambiguities in existing regulation).

62. *See* Scott, *supra* note 58, at 313 ("[G]eoengineering creates a clear risk of serious harm to the transboundary and global environment; it utilizes common spaces such as the high seas, atmosphere, or outer space; and it has yet to be addressed . . . in any regulatory forum.").

63. *See id.* at 330 (explaining the need to analyze international environmental law as it pertains to climate engineering using aggregate principles developed from various sources of law).

favorable toward climate engineering research.[64] Even in the case of deployment, scientists' current understanding is that the expected negative side effects of climate engineering would be much less severe than climate change alone.[65] Given this understanding, carefully conducted field research—although it may present risks of its own to humans and the environment—would help us understand the extent to which climate engineering may be a beneficial option.[66] Field research may be particularly valuable if climate change is more severe than expected, if damages from climate change are greater than expected, if we are unable to adapt society and the environment, or if future emissions reductions are significantly suboptimal.[67] Furthermore, recall that "almost all justifications for international environmental protection are predominantly and in some sense anthropocentric."[68] The norms, rights, and obligations of international environmental law reveal that, for the most part, States are committed to the protection of humans and the environments that we value.[69] Unsurprisingly, economic considerations are dominant, and even non-economic considerations, such as cultural and aesthetic benefits, are valued through a human perspective.[70]

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64. *See infra* Parts IV–VI (arguing that climate engineering research is permissible under current international environmental law).

65. *See* IPCC, PHYSICAL SCIENCE, *supra* note 1, at 7-5 ("Models consistently suggest that SRM would generally reduce climate differences compared to a world with elevated greenhouse gas concentrations and no SRM . . . ."); *see also* Juan B. Moreno-Cruz et al., *A Simple Model to Account for Regional Inequalities in the Effectiveness of Solar Radiation Management*, 110 CLIMATIC CHANGE 649, 649 (2012) ("We find that an SRM scheme optimized to restore population-weighted temperature changes to their baseline compensates for 99% of these changes while an SRM scheme . . . compensates for 97% of these changes. Hence, while inequalities in the effectiveness of SRM are important, they may not be as severe as . . . assumed.").

66. *See* BIPARTISAN POLICY CENTER'S TASK FORCE ON CLIMATE REMEDIATION, GEOENGINEERING: A NATIONAL STRATEGIC PLAN FOR RESEARCH ON THE POTENTIAL EFFECTIVENESS, FEASIBILITY, AND CONSEQUENCES OF CLIMATE REMEDIATION TECHNOLOGIES 3 (2011) (advocating for climate engineering research "to be able to judge whether particular climate remediation techniques could offer a meaningful response to the risks of climate change").

67. *See generally* Juan B. Moreno-Cruz & David W. Keith, *Climate Policy Under Uncertainty: A Case for Solar Geoengineering*, 121 CLIMATIC CHANGE 431 (2012) (modeling the benefits of climate engineering research based on the uncertain amount of climate change for a given increase in greenhouse gas concentrations).

68. PATRICIA W. BIRNIE ET AL., INTERNATIONAL LAW AND THE ENVIRONMENT 7 (2009).

69. *See id.* at 7–8 (discussing the anthropocentric orientation of international environmental law).

70. *See* Scott, *supra* note 58, at 357 ("The integration of human and nature that characterizes the Anthropocene has implicitly been recognized by the application of the core principles of international environmental law to all activities likely to have a significant impact on the environment . . . .").

This climate change/climate engineering tension is particularly relevant because greenhouse gases and climate change often meet the definitions of "pollution" or "adverse effects," which the MEAs examined below seek to reduce.[71] Whether greenhouse gases, which harm humans and the environment only indirectly, should be considered to be pollution is not immediately obvious, and has been examined surprisingly little. Several authors have concluded that greenhouse gases do indeed meet the criteria for "pollution of the marine environment"[72] under the UN Convention on the Law of the Sea (UNCLOS),[73] and nearly identical definitions are used in the Convention on Long-Range Transboundary Air Pollution (LRTAP Convention)[74] and the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR).[75] Furthermore, there is an emerging discourse as to whether States may be responsible and potentially liable for greenhouse gas emissions.[76] At the domestic level,

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71. *See* UNFCCC, *supra* note 20, art. 1, para. 1 ("'Adverse effects of climate change' means changes in the physical environment or biota resulting from climate change which have significant deleterious effects on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare.").

72. *See, e.g.*, Richard S. J. Tol & Roda Verheyen, *State Responsibility and Compensation for Climate Change Damages—A Legal and Economic Assessment*, 32 ENERGY POL'Y 1109, 1117 (2004) (concluding that greenhouse gases meet the UNCLOS definition of pollution of the marine environment); Meinhard Doelle, *Climate Change and the Use of the Dispute Settlement Regime of the Law of the Sea Convention*, 37 OCEAN DEV. INT'L L. 319, 322 (2006) ("[I]t would seem that human-induced GHG emissions fit within the definition of marine pollution in UNCLOS . . . .").

73. United Nations Convention on the Law of the Sea, art. 1.1.4, Dec. 10, 1982, 1833 U.N.T.S. 3 [hereinafter UNCLOS] ("[P]ollution of the marine environment means the introduction by man . . . of substances or energy into the marine environment . . . which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities . . . .").

74. Convention on Long-Range Transboundary Air Pollution art. 1, Nov. 13, 1979, 1302 U.N.T.S. 219 [hereinafter LRTAP Convention] ("Air pollution means the introduction . . . of substances or energy into the air resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems . . . and impair or interfere with amenities and other legitimate uses of the environment . . . ."); *see also* PHILIPPE SANDS & JACQUELINE PEEL, PRINCIPLES OF INTERNATIONAL ENVIRONMENTAL LAW 247 (3d ed. 2012) ("The definition of 'air pollution' is broad enough to include atmospheric emissions of greenhouse gases and ozone-depleting substances as 'air pollutants' . . . . ").

75. Convention for the Protection of the Marine Environment of the North-East Atlantic, art. 1(d), Sept. 22, 1992, 2354 U.N.T.S. 67 [hereinafter OSPAR Convention] ("'Pollution' means the introduction by man, directly or indirectly, of substatnces or energy into the maritime area which results, or is likely to result, in hazards to human health, harm to living resources and marine ecosystems, damage to amenities or interference with other legitimate uses of the sea.").

76. *See* CLIMATE CHANGE LIABILITY 9 (Michael Faure & Marjan Peeters eds., 2011) (addressing "the question to what extent actions taken, mostly by public authorities, based on the precautionary principle could specifically lead to liability"); *see generally* CLIMATE

whether greenhouse gases are "air pollutants" under the Clean Air Act (CAA) was central to a U.S. Supreme Court case, which ruled that the Environmental Protection Agency (EPA) has the authority to regulate greenhouse gases.[77] Vague terms in various MEAs may also raise the climate change/climate engineering tension. Specifically, climate change may satisfy the mostly undefined terms such as "damage" or "adverse effects" found in the Vienna Convention for the Protection of the Ozone Layer,[78] the Antarctic Treaty System's Madrid Protocol,[79] and the Convention on Biological Diversity (CBD).[80] Similarly, commitments to protect the environment often imply that States should consider innovative actions such as climate engineering in order to do so.[81]

The third matter is that the legal implications for research are different from those of deployment. Scientific research is encouraged by

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CHANGE LIABILITY: TRANSNATIONAL LAW AND PRACTICE (Richard Lord et al. eds., 2011) (discussing liability for state action or inaction as it pertains to addressing the effects of climate change).

77. *See* Massachusetts v. Envtl. Prot. Agency, 549 U.S. 497, 534 (2007) (concluding that under the Clean Air Act, the EPA has the power to regulate carbon emissions from motor vehicles as air pollutant agents that contribute to climate change).

78. Vienna Convention for the Protection of the Ozone Layer, art. 1.2, *opened for signature* Mar. 22, 1985, 1513 U.N.T.S. 293 [hereinafter Vienna Convention] ("'Adverse effects' means changes in the physical environment or biota, including changes in climate, which have significant deleterious effects on human health or on the composition, resilience and productivity of natural land managed ecosystems, or on materials useful to mankind.").

79. Protocol on Environmental Protection to the Antarctic Treaty, art. 3.2, Oct. 4, 1991, 30 I.L.M. 1461 [hereinafter Madrid Protocol] (prohibiting "activities that result in adverse effects on climate or weather patterns, significant adverse effects on air or water quality, significant changes in the atmospheric, terrestrial (including aquatic), glacial or marine environments, and further jeopardy to endangered or threatened species or populations of such species").

80. Convention on Biological Diversity, arts. 7(c), 8, *opened for signature* June 5, 1992, 1760 U.N.T.S. 79 [hereinafter CBD] ("Each contracting party shall identify processes and categories of activities which have or are likely to have significant adverse impacts on the conservation and sustainable use of biological diversity, and monitor their effects through sampling and other techniques.").

81. *See* Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, art. III.2, Dec. 10, 1976, 1108 U.N.T.S. 151 [hereinafter ENMOD] ("The State parties to this Convention undertake to facilitate, and have the right to participate in, the fullest possible exchange of scientific and technological information on the use of environmental modification techniques for peaceful purposes."); *see also* Declaration of the United Nations Conference on the Human Environment, para. 7, June 16, 1972, 11 I.L.M. 1416 [hereinafter Stockholm Declaration] ("Man has the fundamental right to freedom, equality and adequate conditions of life, in an environment of a quality that permits a life of dignity and well-being, and he bears a solemn responsibility to protect and improve the environment for present and future generations.").

numerous multilateral agreements, environmental and non-environmental.[82] These regulations are dominated by guidelines and other forms of soft law, frequently developed by expert, non-state bodies.[83] Some scholars assert that there is a right to conduct research, although even this would be limited by risks to others and the environment.[84] Some treaties, such as those concerning potential weapons of mass destruction, do not directly address research but implicate it in their implementation.[85] Research is referenced only in passing in other agreements, such as the International Convention for the Regulation of Whaling,[86] but has become a central issue in the implementation of these treaties.[87] Among the MEAs examined here, only UNCLOS and the Madrid Protocol contain detailed provisions governing scientific research.[88]

In the case of climate engineering, the differences between research and its deployment are due to the smaller scale of research, the lower state of knowledge present during research, the generation of knowledge, and

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82. *See infra* text accompanying notes 125–126 (UNFCCC), 170, 176 (Vienna Convention), 146–147 (ENMOD), 183 (LRTAP Convention), 198 (Oslo Protocol), 210 (Outer Space Treaty), 241–244 (UNCLOS), 293,–300 (Antarctica Treaty), 318 (OSPAR Convention), 367 (Stockholm Declaration), 374 (Rio Declaration).

83. *See, e.g.*, *Ethical Principles for Medical Research Involving Human Subjects*, WORLD MED. ASS'N, http://www.wma.net/en/30publications/10policies/b3/ (last visited Mar. 22, 2014) (providing ethical guidelines for medical practitioners and researchers when using human subjects in research and testing) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

84. *See* Arjun Appadurai, *The Right to Research*, 4 GLOBAL SOC. EDUC. 167, 168 (2006) (arguing that there is a universal and fundamental right for all humans to research and gather knowledge); *see also* Mark Brown & David Guston, *Science, Democracy, and the Right to Research*, 15 SCI. ENG. ETHICS 351, 359 (2009) ("Non-scientists are also more likely to accept the notion of a right to do research if it is explicitly coupled with an acknowledgement that the preservation of this right depends on scientists fulfilling its corresponding obligations.").

85. *See, e.g.*, Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction, Apr. 10, 1972, 26, U.S.T. 583, 1015 U.N.T.S. 163 (outlining the policies and procedures necessary for any country wishing to develop, produce, or stockpile weapons of mass destruction).

86. *See* International Convention for the Regulation of Whaling, art. VIII, Dec. 2, 1946, 161 U.N.T.S. 72 ("[A]ny contracting government may grant to any of its nationals a special permit authorizing that national to kill, take and treat whales for purposes of scientific research subject to such restrictions as to number and subject to such other conditions as the Contracting Government thinks fit.").

87. *See, e.g.*, *id.* (regulating whaling).

88. *See* UNCLOS, *supra* note 73, art. 87, ¶¶ 238–65 (establishing the freedom to conduct scientific research in the high seas so long as the interests of other States are considered before research begins); Antarctic Treaty, pmbl, art. I-III, IX, Dec. 1, 1959, 204 U.N.T.S. 71 (establishing the use of Antarctica for, *inter alia*, scientific purposes).

(possibly) the intent.[89] Regarding scale, field tests will generally be designed to impact a smaller region at a lesser intensity for a shorter duration than full deployment, and any resulting damage to humans or the environment should likewise be lesser, perhaps not meeting the threshold for the applicable law.[90] With respect to the state of knowledge during research, the risks posed by field tests may remain uncertain at the time they are carried out.[91] The then-current state of knowledge will consequently be germane to whether a given test would be considered likely to harm humans or the environment. Furthermore, the tests are intended to generate knowledge through scientific research, which is encouraged by some of the MEAs discussed below. Finally, although the intent of scientists could potentially help distinguish between field research and deployment, it will be of little significance because international environmental law is rarely concerned with intent.[92]

As an extension of the research-deployment distinction, the category of "risky climate engineering field research" will not always be discrete in two dimensions of comparison. "Vertically" it may be difficult to distinguish those tests that pose no real risk from those which do, as well as distinguishing large-scale field research from actual deployment.[93]

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89. *See generally* David R. Morrow et al., *Toward Ethical Norms and Institutions for Climate Engineering Research*, 4 ENVTL. RESEARCH LETTERS 045106 (2009) (distinguishing climate engineering research from climate engineering deployment based on environmental impacts, timeline, and "the intentions of those carring out the [climate engineering] activity").

90. *See* Parson & Keith, *supra* note 56, at 1279 (discussing the limited scale of research).

91. *See* MacMynowski et al., *supra* note 54, at 5044 (estimating the intensity of SRM required in a large-scale field test and the possible resulting changes in precipitation).

92. *See* Morrow, et. al., *supra* note 89, at 045106 ("Thus, the difference between CE research and CE practice lies in the intentions of those carrying out the CE activity."). At least in the case of CDR, there may be a distinction between research and deployment based on whether there is an intent to gain financial benefit. Indeed, the nascent international regulatory framework for ocean fertilization requires that "legitimate scientific research" have no direct financial benefits for the researcher. *See infra* Part IV.H (describing the LC-LP's prohibition against ocean dumping and its exception for "legitimate scientific research"). Similarly, a recent field experiment explicitly examined marine cloud formation and climate in general, but had clear implications for MCB SRM. *See generally* Lynn M. Russell et al., *Eastern Pacific Emitted Aerosol Cloud Experiment*, 94 BULL. AM. METEOROLOGICAL SOC'Y 709 (2013) (describing aerosol effects on warm-cloud microphysics).

93. *See* Alan Robock et al., *A Test for Geoengineering?*, 327 SCIENCE 530, 530 (2012) ("We argue that geoengineering cannot be tested without full-scale implementation."); b*ut see* MacMynowski et al, *supra* note 54, at 5045 ("[O]ur results demonstrate that useful knowledge can be obtained without full-scale implementation.").

"Laterally," it may be difficult to distinguish outdoor research from similar topics that resemble—but are not—climate engineering.[94]

The fourth legal matter is the function of law. Regulation in general can be called "the sustained and focused attempt to alter the behavior of others according to defined standards or purposes with the intention of producing a broadly defined outcome or outcomes."[95] Thus, regulation can both encourage and discourage certain actions.[96] Indeed, law has enablement and facilitation among its functions, and has obligations, incentives, and exhortations among its tools.[97] Yet, regulation is too often framed as being only restrictive.[98]

Fifth, it is with respect to these previous three aspects—the climate change/climate engineering tension, the differences between research and deployment, and the enabling function of law—that the existing legal literature concerning climate engineering, although enlightening, remains limited. A number of scholars have reviewed how international law may restrict a State's deployment of climate engineering.[99] These scholars

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94. *See* Morrow, et. al., *supra* note 89, at 045106 ("[T]he technologies developed or made possible through . . . research may be deployed in ways intended to cause harm. We can foresee some of these ways, but not all."). For example, a "rogue" researcher claimed that his ocean fertilization was to increase the stock of salmon, which feed on phytoplankton. This may have allowed him to comply with the letter, but not the spirit, of international law. *See* Neil Craik et al., *Regulating Geoengineering Research through Domestic Environmental Protection Frameworks: Reflections on the Recent Canadian Ocean Fertilization Case*, CARBON & CLIMATE L. REV. 117, 117–18 (2013) ("The principals involved in the activity characterized it as an ocean 'restoration' project . . . . However, they also made public statements indicating that they planned to generate revenue.").

95. Julia Black, *Decentering Regulation: Understanding the Role of Regulation and Self Regulation in a "Post-Regulatory" World*, 54 CURRENT LEGAL PROBLEMS 103, 142 (2001).

96. *See* ANTHONY OGUS, REGULATION: LEGAL FORM AND ECONOMIC THEORY 1 (1994) ("[T]he state seeks to encourage or direct behaviour which it is assumed would not occur without such intervention.").

97. *See id.* (addressing how regulation can cause parties to act in certain ways).

98. *See*, *e.g.*, BLACK'S LAW DICTIONARY 1398 (9th ed. 2009) (defining "regulation" as the "act or process of controlling by rule or restriction").

99. *See, e.g.*, Daniel Bodansky, *May We Engineer the Climate?*, 33 CLIMATIC CHANGE 309, 310 (1996) (analyzing the legal restrictions on climate engineering); *see also* Ralph Bodle, *Geoengineering and International Law: The Search for Common Legal Ground*, 46 TULSA L. REV. 305, 308 (2010) (reviewing sources of international law that effect the permissibility of climate engineering); Rex J. Zedalis, *Climate Change and the National Academy of Sciences' Idea of Geoengineering: One American Academic's Perspective on First Considering the Text of Existing International Agreements*, 19 EUR. ENERGY ENVTL. L. REV. 18, 20 (2010) (critiquing the nature of international agreements and the attitude toward climate engineering); Catherine Redgwell, *Geoengineering the Climate: Technological Solutions to Mitigation-Failure or Continuing Carbon Addiction?*, 5 CARBON & CLIMATE L. REV. 178, 181–88 (2011) (describing the limitations imposed by the current legal regime); Gerd Winter, *Climate Engineering and International Law: Last Resort or the End of*

generally overlook the more urgent topic of field research, the fact that international law enables field research, and that the purpose of climate engineering would be to reduce climate change risks.[100]

Sixth, not all risks are alike. Specifically, those risks discussed above can be conceptualized on a rough spectrum from environmental to social in character. Changes to precipitation due to SRM and ecological impacts from ocean fertilization are, for the most part, environmental risks.[101] Technological momentum and a "slippery slope" from research to deployment are relatively social risks.[102] International environmental law could be an effective set of tools for reducing the former group.[103] On the other hand, the management of the more social risks will call for a broader set of innovative legal and non-legal means in international, transnational, and national settings, possibly including international environmental law but likely relying more heavily on a plurality of diverse means.[104]

As a final note, it must be remembered that international law is not implemented solely through literal readings of treaty texts. Instead, it is self-enforced and enforced internationally through political channels among countries of unequal power, reputation, and interests.[105] An act by a

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Humanity?, 20 REV. EUR. COMM. & INT'L ENVTL. L. 277, 279 (2011) (explaining the effects of law on climate engineering activity); David A. Wirth, *Engineering the Climate: Geoengineering as a Challenge to International Governance*, 40 B.C. ENVTL. AFF. L. REV. 413, 421–24 (2013) (describing the limits imposed by the current legal framework on climate engineering proposals); Scott, *supra* note 58 (reviewing possible contradictions in international law presented by climate engineering).

100. *See, e.g.*, Winter, *supra* note 99, at 288 (concluding normatively that "large-scale research of SRM must be prohibited from the outset").

101. *See* Press Release, European Geosciences Union, Geoengineering Could Disrupt Rainfall Patterns (June 6, 2012), *available at* http://www.egu.eu/news/4/geoengineering-could-disrupt-rainfall-patterns/ ("Under the scenario studied, rainfall strongly decreases . . . . Overall, global rainfall is reduced by about five percent on average in all four models studied.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

102. *See* SOLAR RADIATION MANAGEMENT GOVERNANCE INITIATIVE, SOLAR RADIATION MANAGEMENT: THE GOVERNANCE OF RESEARCH 21 (2011), *available at* http://www.srmgi.org/report/ ("Even very basic . . . research into SRM could be a first step onto a 'slippery slope' towards deployment. Research could create momentum for development of SRM technology, as well as . . . lobbying . . . [which] could use its influence to override moral and other objections or to unduly influence public opinion.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

103. *See id.* at 35 (describing international environmental instruments and institutions as a method of governance).

104. *See*, *e.g.*, *id.* at 35–37 (listing additional forms of governance, including "a collection of independent national policies" and "a non-governmental, transnational code of conduct").

105. *See* Richard H. Steinberg, *Wanted: Dead or Alive—Realist Approaches To International Law*, *in* INTERDISCIPLINARY PERSPECTIVES ON INTERNATIONAL LAW AND INTERNATIONAL RELATIONS: THE STATE OF THE ART 146, 150 (Jeffrey L. Dunoff & Mark A.

responsible member of the international community, which technically is contrary to an MEA but which other members view favorably, is unlikely to be condemned.[106] Likewise, a willful act by a so-called rogue state which violates no international law, but may have negative impacts on other countries, will be condemned.[107] Although this article uses a rather literal reading, this is intended as a starting point and will not necessarily perfectly reflect reality.

IV. Binding Multilateral Environmental Agreements

Binding MEAs constitute the most important source of international environmental law. This section reviews those MEAs that will likely have the most impact on climate engineering field research. For the sake of brevity and focus, this review is limited in three ways: to agreements concerned with environmental protection (even though other domains such as human rights may be relevant); to those agreements that are pertinent to climate engineering research; and to global agreements or MEAs that cover a large geographical areas. Although no MEAs directly address climate engineering, their objectives, commitments, and hortatory statements both reflect and influence state behavior, illuminating the norms of the international community.[108] This review will require an exercise in treaty interpretation.[109] Of course, MEAs are not merely isolated collections of

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Pollack eds., 2013) (arguing that "international law reflects the interests of powerful states" and that "if an international law contradicts the long-term interests of a powerful state, then it will not comply with it").

106. *See*, *e.g.*, INDEPENDENT INTERNATIONAL KOSOVO COMMISSION, THE KOSOVO REPORT 186 (2000) ("The Commission concludes that the NATO military intervention was illegal but legitimate.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

107. *See* Anthony C. Arend, *International Law and Rogue States: The Failure of the Charter Framework*, 36 NEW ENG. L. REV. 735, 735–36 (discussing the ramifications of a rogue State's actions that do not violate international law but are still disapproved of by the international community); Daniel H. Joyner, *Iran's Nuclear Program and International Law*, 2 PENN. ST. J.L. & INT'L AFF. 237 (2013) (arguing that Iran's nuclear program complies with international law, despite condemnation by Western countries and the International Atomic Energy Agency).

108. *See* David G. Victor, *Enforcing International Environmental Law: Implications for an Effective Global Warming Regime*, 10 DUKE ENVTL. L. & POL'Y F. 147, 151 (Fall 1999) ("More than 140 multilateral environmental agreements govern behavior related to dozens of international environmental issues. . . . [D]espite the rarity of enforcement mechanisms, generally countries have complied with their international environmental commitments.").

109. *See* Vienna Convention on the Law of Treaties, arts. 31–33, *opened for signature* May 23, 1969, 1155 U.N.T.S. 331 (providing that a treaty is to be interpreted in good faith, within its legal context, and in a manner consistent with its objectives; that words are to be

words. Although intergovernmental and national institutions that operate in a complex political reality implement them, this paper emphasizes the actual texts of these documents.

A. United Nations Framework Convention on Climate Change

The UN Framework Convention on Climate Change (UNFCCC) is the most important document in international environmental law regarding climate engineering because of its subject matter, its global participation, and its robust institutional support.[110] Its objective is not merely to prevent dangerous climate change, but to do so in a manner that is balanced with other anthropocentric and environmental desiderata:

> The ultimate objective . . . is . . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.[111]

Likewise, the key phrase "adverse effects of climate change" encompasses harm both to the environment and "the operation of socio-economic systems or . . . human health and welfare."[112] Similarly, the UNFCCC's first principle indicates that a chief reason to minimize climate change is anthropocentric: "The Parties should protect the climate system for the benefit of present and future generations of humankind."[113] This MEA does not limit states' actions in meeting its objectives to its commitments, implying that states may do so by other means.[114]

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understood in their ordinary meaning; and that ambiguities may be clarified through preparatory documents and "the circumstances of its conclusion").

110. *See* Lakshman Guruswamy, *Energy Justice and Sustainable Development*, 21 COLO. J. INT'L ENVTL. L. & POL'Y 231, 233–34 n.5 (2010) (discussing the wide acceptance of the UNFCCC based on its ratification by 194 States).

111. UNFCCC, *supra* note 20, art. 2.

112. *Id*. art. 1.1.

113. *Id*. art. 3.1.

114. *See id.* art. 4.2(a) ("Each of these Parties shall adopt national policies and take corresponding measures . . . . These Parties may implement such policies and measures jointly with other Parties and may assist other Parties in contributing to the achievement of the objective of the Convention . . . .").

At a minimum, the UNFCCC supports research into CDR, including ocean fertilization. In its text, Parties commit to stabilize greenhouse gases through both the reduction of emissions and the enhancement of sinks and reservoirs, which is defined to include oceans and the biological pump.[115] Three separate commitments obligate Parties to mitigate the adverse effects of climate change through such sinks and reservoirs.[116] Two of these commitments include the enhancement of sinks and reservoirs, and one explicitly refers to oceans: "All Parties . . . shall . . . promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouses gases not controlled by the Montreal Protocol, including . . . oceans as well as other . . . marine ecosystems."[117] These goals are furthered by the agreement's Kyoto Protocol, which, although focused on emission reduction, commits Parties to further the Protocol's objectives by researching and promoting "carbon dioxide sequestration technologies and . . . advanced and innovative environmentally sound technologies."[118]

The UNFCCC is less clear with respect to the development of SRM, which would not further the agreement's objective of stabilizing greenhouse gas concentrations.[119] Two general conclusions of scientific research must be highlighted before examining specific provisions. First, humans will soon be, or perhaps already are, committed to a magnitude of future climate change that is "dangerous" because it will threaten

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115. *See id*. arts. 1.7, 1.8, 4.1, 4.2. (defining a reservoir as "a component or components of the climate system where a greenhouse gas or a precursor of a greenhouse gas is stored" and a sink as "any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere").

116. *See id.* arts. 4.1(b), 4.1(d), 4.2(a) (setting out the different obligations of parties to mitigate adverse climate change).

117. *Id*. arts. 4.1(d), 4.2(a).

118. Kyoto Protocol to the United Nations Framework Convention on Climate Change, Dec. 11, 1997, 2303 U.N.T.S. 148, art. 2.1(a)(iv); *see also id.* art. 10(c) (requiring Parties to "[c]ooperate in the promotion of effective modalities for the development, application and diffusion of, and take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies").

119. *See* UNFCCC, *supra* note 20, art. 2 ("The ultimate objective of this Convention . . . is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."); THE ROYAL SOCIETY, *supra* note 25, at 24 ("While SRM methods might therefore help to mitigate against a rise in global mean surface temperature, they do nothing directly to reduce atmospheric concentrations of CO_2, or the rate at which they are increasing.").

ecosystems, food production, and sustainable economic development.[120] Second, current models indicate that potential SAI or MCB deployment would be rapid and relatively inexpensive.[121]

Several passages in the UNFCCC indicate a relatively favorable position regarding SRM research. As quoted above, the UNFCCC's objective calls for some urgency, given the expected onset of significant climate change.[122] Furthermore, another principle of the UNFCCC states that "[t]he Parties should . . . tak[e] into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost."[123] Similarly, a more strongly-worded commitment states that Parties "shall . . . employ appropriate methods . . . with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change."[124] From these provisions, SRM could be understood to be a form of adaptation, albeit an extreme one. Finally, multiple passages call for the development and diffusion of technology and research, further implying a positive stance toward climate engineering research.[125] For example:

> All Parties . . . shall . . . Promote and cooperate in scientific, technological, technical, socio-economic and other research . . . intended to further the understanding and to reduce or eliminate the remaining uncertainties regarding . . . the economic and social consequences of various response strategies; [and] Promote and cooperate in the full, open and prompt exchange of relevant scientific, technological, [and] technical . . . information related

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120. *See* Morrow et al., *supra* note 89, at 045106 ("With regard to the moral hazard, unless scientists take great care in what experiments they do, what they publish, and how they explain their work, the public and policy makers may develop an optimistic bias . . . . If this happens, hope for a technological fix for climate change may cripple efforts to limit greenhouse gas emissions.").

121. *See* THE ROYAL SOCIETY, *supra* note 25, at 24–33 (noting the low estimated costs of several SRM techniques). Estimates for the financial cost of SRM to counterbalance the warming effect of a doubling of atmospheric carbon dioxide range from approximately $1 billion to $100 billion per year. *See generally* Gernot Klepper & Wilfried Rickels, *The Real Economics of Climate Engineering*, ECON. RESEARCH INT'L 316564 (2012) (discussing the financial costs of climate engineering).

122. *See supra* note 111 and accompanying text (stating the objectives of the UNFCCC).

123. UNFCCC, *supra* note 20, art. 3.3.

124. *Id*. art. 4.1(f).

125. *See id*. arts. 4.3, 4.7, 4.8, 4.9, and 11.1 (requiring Parties to develop and diffuse new technologies and to engage in research).

> to . . . the economic and social consequences of various response strategies.[126]

The UNFCCC invokes two applicable principles of international environmental law, both of which point favorably to climate engineering research. First, efforts to minimize climate change must be done according to common but differentiated responsibilities.[127] Climate engineering research is consistent with this, as exclusively industrialized countries presently fund it, which is likely to continue for the foreseeable future.[128] Meanwhile all countries, especially the less developed ones, which are on average more vulnerable to climate change, could benefit from the increased knowledge of possible alternative responses to climate change.[129] Second, the UNFCCC invokes the precautionary principle:

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126. *Id*. art. 4.1(g) and (h); *see also* arts. 5, 9.2 (stating that the phrase "response strategies" is undefined but presumably could include responses other than those encouraged by the UNFCCC).

127. *See id*. pmbl. ¶ 6, art. 3.1, 4.1 (discussing action needed to minimize climate change).

128. *See* Andrew Parker & David Keith, *Public Research Funds Committed To Geoengineering Research Projects* (Oct. 31, 2012), http://environment.harvard.edu/sites/default/files/srm_projects_around_the_world.pdf (indicating that climate engineering research projects are publicly-funded in Austria, Finland, France, Germany, Japan, Norway, and the United Kingdom) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

129. *See* UNFCCC, *supra* note 20, pmbl. (recognizing that developing countries "are particularly vulnerable to the adverse effects of climate change"). This assumes open publications of results and minimal intellectual property claims, which appear to be emerging norms, especially for SRM. *See generally* Michael MacCracken et al., THE ASILOMAR CONFERENCE RECOMMENDATIONS ON PRINCIPLES FOR RESEARCH INTO CLIMATE ENGINEERING TECHNIQUES (2010), *available at* http://www.climate.org/PDF/AsilomarConferenceReport.pdf (calling for open and cooperative climate engineering research) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); BIPARTISAN POLICY CENTER'S TASK FORCE ON CLIMATE REMEDIATION, GEOENGINEERING: A NATIONAL STRATEGIC PLAN FOR RESEARCH ON THE POTENTIAL EFFECTIVENESS, FEASIBILITY, AND CONSEQUENCES OF CLIMATE REMEDIATION TECHNOLOGIES (2011), *available at* http://bipartisanpolicy.org/library/report/task-force-climate-remediation-research (advocating open and interdisciplinary research efforts) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); Steve Rayner et al., *The Oxford Principles*, 121 CLIMATIC CHANGE 499 (2013) (proposing norms for climate engineering and its research, including open publication of results and minimal patents on SRM technologies); *see also* Anne C. Mulkern, *Researcher: Ban Patents on Geoengineering Technology*, CLIMATEWIRE (Apr. 18, 2012), http://www.scientificamerican.com/article.cfm?id=researcher-ban-patents-on-geoengineering-technology (quoting a prominent climate engineering researcher calling for no patents on SRM technologies) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

> Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and *mitigate its adverse effects*. Where there are threats of serious or irreversible damage, *lack of full scientific certainty should not be used as a reason for postponing such measure*s, taking into account that policies and measures to deal with climate change *should be cost-effective* so as to ensure global benefits at the lowest possible cost . . . .[130]

The drafters of the UNFCCC likely intended that this principle refer to the scientific uncertainty surrounding climate change and its causes. More than twenty years later, however, there is much less uncertainty concerning climate change, yet lingering uncertainty regarding potential responses.[131] As an analogous example, the precautionary principle could encourage hypothetical large multilateral investment in alternative energy research, which is a possible yet scientifically uncertain response. Along similar lines, this passage can also offer a precautionary case for climate engineering research, in which CDR research would be a precautionary measure toward minimizing the causes of climate change, and SRM research would be one toward mitigating its adverse effects.[132]

The UNFCCC also addresses transboundary environmental harm. In the preamble it notes States' obligations to prevent environmental harm, and the agreement later calls for the minimization of the adverse effects of combating climate change.[133] The UNFCCC thus invokes customary international law coupled with a commitment to consider minimizing adverse effects.[134] States would thus need to undertake certain procedures,

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130. UNFCCC, *supra* note 20, art. 3.3 (emphasis added).

131. *See* IPCC, PHYSICAL SCIENCE, *supra* note 1, § TS.2.1 (discussing advancements in scientists' understanding of the climate change and its causes); Alejandro E. Camacho, *Adapting Governance to Climate Change: Managing Uncertainty Through a Learning Infrastructure*, 59 EMORY L.J. 4, 10 (2009) ("Extensive evidence confirms that global climate change is already occurring . . . . Yet the extent of these impending impacts and the exact future distribution of impacts globally and domestically are far from clear.").

132. *See generally* Jesse L. Reynolds & Floor Fleurke, *Climate Engineering Research: A Precautionary Response to Climate Change?*, 2 CARBON & CLIMATE L. REV. 101 (2013) (arguing that the exercise of precaution, particularly as it is embodied in the UNFCCC, calls for climate engineering research).

133. *See* UNFCCC, *supra* note 20, pmbl. (recalling states' "responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction"); *id.* art. 4.1(f) (requiring States to minimize adverse effects of projects or measures undertaken to mitigate or adapt to climate change).

134. *See id.* art. 3, para. 3 ("The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects.").

including notification, consultation, and cooperation, as well as (arguably) impact assessment and subsequent monitoring prior to large-scale climate engineering field tests that may have transboundary impacts.[135]

One possible obstacle for climate engineering research is the UNFCCC's prioritization of emissions reductions and the enhancement of sinks and reservoirs, processes, which are not affected by SRM.[136] Although the UNFCCC does necessarily exclude other methods of climate engineering, it could theoretically condemn climate engineering research if it were to undermine the goal of emissions reductions by reducing the political willpower for the reductions.[137] This interpretation, however, requires both the implausible evidence of the basis of decision-makers' behavior and a radical treaty interpretation wherein a complementary action would be prohibited if it lessened the magnitude of a committed action.[138]

Independent of the UNFCCC's text, its related institutions are the most likely sites for the top-down development of international norms and rules governing climate engineering research.[139] This is due to the close relevance of the agreement's subject matter, its universal participation, and the bodies created by it, including the Conference of Parties (COP), Secretariat, Subsidiary Body for Scientific and Technological Advice, and—subsequently formed by the COP—the Technology Executive Committee.[140]

B. Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques

The Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) is another highly pertinent MEA, as it is the only binding treaty that directly addresses intentional climatic interventions.[141] Most industrialized countries are

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135. *See id.* art. 4, paras. 1(e), (g), (h), (i), (j) (summarizing procedural responsibilities of the Parties).

136. *See* UNFCCC, *supra* note 20, art. 4.1(b) and (d) (prioritizing the use of sinks and reservoirs to reduce greenhouse gases in the atmosphere).

137. *See* Winter, *supra* note 99, at 288 (arguing that "large-scale research of SRM must be prohibited from the outset" because, *inter alia*, "interpretation the law prohibits measures [i.e. climate engineering] that weaken the implementation of Plan A [i.e. emissions reduction]").

138. *See id.* (arguing that customary international law prohibits such an interpretation of the UNFCCC).

139. *See* Bodansky, *supra* note 99, at 313 ("[I]t is likely that the institutions created by the Convention would provide the principal international fora for consideration of climate engineering proposals.").

140. *See id.* (discussing the relevant international bodies).

141. *See* ENMOD, *supra* note 81, art. I.1, III.1 (describing the purpose of ENMOD).

Parties to this Convention, but it is considered to be a dormant instrument, with neither supporting institutions nor regular meetings.[142] Even more so than with the UNFCCC, a careful reading of the text reveals a favorable legal setting for climate engineering research. Although the definition of "environmental modification techniques" includes many forms of climate engineering,[143] ENMOD prohibits only "engag[ing] in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other State Party."[144] ENMOD does not prohibit the research and development of potentially hostile environmental modification techniques, and it explicitly states that it "shall not hinder the use of environmental modification techniques for peaceful purposes."[145] Moreover, ENMOD recognizes and encourages peaceful environmental modification: "[Parties] [r]ealiz[e] that the use of environmental modification techniques for peaceful purposes could improve the interrelationship of man and nature and contribute to the preservation and improvement of the environment for the benefit of present and future generations . . . ."[146] Parties are to exchange scientific information regarding peaceful environmental modification, and those with the financial means "shall contribute . . . to international economic and scientific co-operation in the preservation, improvement and peaceful utilization of the environment . . . ."[147] If "the preservation, improvement and peaceful utilization of the environment" were to include reducing climate change risks, the passage could even be interpreted as an obligation for industrialized Parties to "contribute" to climate engineering research.

If a Party were to assert that another's climate engineering field research were hostile and damaging, a complaint under ENMOD would be

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142. *See* Arunabha Gosh & Jason Blackstock, *Does Geoengineering Need a Global Response—and of What Kind? International Aspects of SRM Research Governance* (SRMGI, background paper, 2011), *available at* http://www.srmgi.org/files/2011/09/SRMGI-International-background-paper.pdf ("[ENMOD] has had only two review conferences (1984 and 1992) which updated the convention only with non-binding 'understandings,' the bulk of its ratifications came in the 1970s and 1980s . . . and attempts by the General Assembly to have it universally ratified have come to naught.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

143. *See* ENMOD, *supra* note 81, art. II ("[T]he term 'environmental modification techniques' refers to any technique for changing—through the deliberate manipulation of natural processes—the dynamics, composition or structure of the Earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space.").

144. *Id*. art. I.1.

145. *Id*. art. III.1.

146. *Id*. pmbl.

147. *Id*. art. III.2.

difficult to enforce.[148] The damage would need to occur in the environment of the complainant, as ENMOD applies neither to the environments of non-Parties, to that of the country engaged in the activity, nor to that of non-state areas.[149] The document contains only weak enforcement mechanisms.[150] Complaints would be lodged with the UN Security Council, where any of the five permanent members—who are among the States most likely to conduct climate engineering field research—could veto Council action.[151] Finally, ENMOD is an inactive legal instrument, and no complaints have ever been lodged under it. Nevertheless, if "awakened" from its dormant state, it is possible that ENMOD could play a role in facilitating climate engineering research.[152] For example, Parties are to consult and cooperate in resolving problems that may arise in the implementation of the agreement.[153] In addition, its Consultative Committee of Experts could be convened and serve as a forum for the exchange of relevant information and for the development of norms to guide research.[154]

C. Convention on Biological Diversity

The Convention on Biological Diversity (CBD) is an MEA whose significance to climate engineering research is not through its text or specific commitments per se, but instead through its nearly universal participation, its strong institutional support, and the fact that most large scale human endeavors affect biodiversity.[155] Its provisions are broad, and

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148. *See* Charles R. Wunsch, *The Environmental Modification Treaty*, 4 ASILS INT'L L.J. 113, 128–29 (1980) (describing key shortcomings in the enforcement mechanism of ENMOD).

149. *See id.* at 128–29 (explaining the reach of ENMOD).

150. *See id*. at 122 (describing the areas critics have frequently cited).

151. *See* ENMOD, *supra* note 81, art. V ("Any State Party to this Convention which has reason to believe that any other State Party is acting in breach of obligations deriving from the provisions of the Convention may lodge a complaint with the Security Council of the United Nations."); Wunsch, *supra* note 148, at 129 ("The problem is the Security Council's action can be vetoed by one of its five permanent members.").

152. *See* Wunsch, *supra* note 154, at 131 (outlining the potential positive consequences of ENMOD).

153. *See* ENMOD, *supra* note 81, art. V.1 ("The State Parties to this Convention undertake to consult one another and to co-operate in solving any problems which may arise in relation to the objectives of, or in the application of the provisions of, the Convention.").

154. *See id*. art. III.2, V.2 (noting additional means of information dispersement, such as the Consultative Committee of Experts).

155. *See* CBD, *supra* note 80, art. 4 (describing the expansive jurisdictional scope of the treaty); *List of Parties*, CONVENTION ON BIOLOGICAL DIVERSITY, http://www.cbd.int/information/parties.shtml (last visited Mar. 23, 2014) (identifying the

some may apply in the context of climate engineering and its research, such as the call for Parties to identify and to control activities that have "significant adverse impacts" on biodiversity.[156] This presents the climate change/engineering tension, in that both climate change and climate engineering may impact biodiversity. For example, a CBD report concluded that climate engineering "could reduce the magnitude of climate change and its impacts on biodiversity. At the same time, most geoengineering techniques are likely to have unintended impacts on biodiversity."[157]

This connection would have remained somewhat tenuous, had the CBD Conferences of Parties (COP) not addressed climate engineering. At the 2008 COP, Parties urged States to ensure that ocean fertilization CDR not take place until risks and benefits were better understood and regulations were in place, with an exception for "small scale scientific research studies within coastal waters."[158] Two years later, it agreed upon a broader statement concerning all climate engineering, in which it

> [I]nvites Parties and other Governments . . . to consider . . . ensur[ing] . . . in the absence of science based, global, transparent and effective control and regulatory mechanisms for geo-engineering, and in accordance with the precautionary approach and Article 14 of the Convention, that no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the Convention, and only if they are justified by the

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Convention's 193 parties) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

156. *See* CBD, *supra* note 80, art. 7(c) ("Each Contracting Party shall . . . [i]dentify processes and categories of activities which have or are likely to have significant adverse impacts on the conservation and sustainable use of biological diversity, and monitor their effects through sampling and other techniques.").

157. SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, CONVENTION ON BIOLOGICAL DIVERSITY, TECHNICAL SERIES NO. 66: GEOENGINEERING IN RELATION TO THE CONVENTION ON BIOLOGICAL DIVERSITY: TECHNICAL AND REGULATORY MATTERS 14 (Sept. 2012); *see also id.* at 8 (citing climate change as one of the "current main drivers of biodiversity loss").

158. Ninth Meeting of the Conference of Parties to the Convention on Biological Diversity, May 19–30, 2008, *Decision IX/16—Biodiversity and Climate Change* 7, U.N. Doc. UNEP/CBD/COP/DEC/IX/16/C.4 (2008).

> need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment.[159]

Although clearly a statement of caution, it is nonbinding for at least three reasons. First, as described above, the CBD's commitments consistently utilize soft, qualified language. For example, the article invoked by the COP climate engineering decision opens with the phrase "as far as possible and as appropriate."[160] Second, the language of this COP decision uses even weaker language, merely "invit[ing]" countries "to consider" action.[161] Third, the COP does not have the authority to develop binding law.[162]

D. Vienna Convention for the Protection of the Ozone Layer

The Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol on Substances that Deplete the Ozone Layer are germane to climate engineering because SAI SRM using sulfur dioxide, presently the most widely considered injection substance, might damage stratospheric ozone.[163] Presumably, large scale field research into these methods may also have similar effects, and the observation of such impacts could be among the goals of research.[164] The only existing provision contained in these MEAs that may restrict sulfur-based SAI research is that Parties to the Vienna Convention are to implement laws "to control, limit, reduce or prevent human activities . . . [which] have or are likely to have adverse effects resulting from modification or likely modification of the ozone layer[,]" wherein "adverse effects" are environmental changes "including changes in climate, which have significant deleterious effects on

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159. Tenth Meeting of the Conference of Parties to the Convention on Biological Diversity, Oct. 18–29, 2010, *Decision X/33—Biodiversity and Climate Change* 5, U.N. Doc. UNEP/CBD/COP/DECX/33/8(w) (2010).

160. CBD, *supra* note 80, art. 14.

161. Tenth Meeting of the Conference of Parties to the Convention on Biological Diversity, *supra* note 159, at 5.

162. *See* CBD, *supra* note 80, art 23 (describing the powers of the COP, which can initiate binding protocols and amendments, however, they must be ratified by the Parties).

163. *See* Vienna Convention, *supra* note 78, art. 2 (outlining the Convention's commitment to protect human health and the environment from the adverse effects of harm to the ozone layer); R.L. McKenzie et al., *Ozone Depletion and Climate Change: Impacts on UV Radiation*, 10 PHOTOCHEMICAL & PHOTOBIOLOGICAL SCIS. 182, 189 (2011) ("[T]his geo-engineering strategy would increase Arctic ozone depletion during the 21st century and delay Antarctic ozone recovery by 30 to 70 years.").

164. *See* THE ROYAL SOCIETY, *supra* note 25, at 31 (arguing that this method's impact on ozone needs to be studied further).

human health" or the environment.[165] This, however probably will not restrict climate engineering field research, largely due to the climate change/climate engineering tension: climate change itself is expected to impact stratospheric ozone in uncertain ways.[166] In contrast, the effect of SAI SRM on stratospheric ozone remains uncertain and may be relatively small.[167] Furthermore, the aerosol particles would partially block incoming ultraviolet radiation, the increase of which—due to ozone depletion—was the original impetus behind the Vienna Convention.[168] Thus, it is presently unclear whether SAI SRM deployment would cause a net increase or decrease in "adverse effects," but field tests could help resolve this question.[169]

Beyond this, the Vienna Convention, as a framework treaty, has limited commitments, such as to cooperate in relevant scientific research.[170] In contrast, the Montreal Protocol contains stronger provisions, using a "black list" of specific prohibited ozone-depleting substances, which can be (and has been) expanded.[171] If the Parties to the Montreal Protocol were to consider restricting sulfur dioxide SAI SRM research (or deployment), they would need to take into account both its potential benefits and risks. Moreover, if the Parties wished to restrict sulfur dioxide, they would need to implement a novel category dependent upon the purpose, manner, and/or location of emissions, because much larger amounts of sulfur dioxide are already anthropogenically produced while sulfur-based SAI SRM field research would constitute a relatively small contribution.[172]

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165. Vienna Convention, *supra* note 78, art. 1.2, 2.2(b).

166. *See* McKenzie et al., *supra* note 163, at 188 ("[C]hanges in ozone can induce changes in climate, and vice versa.").

167. *See* T.M.L. Wigley, *A Combined Mitigation/Geoengineering Approach to Climate Stabilization*, 314 SCIENCE 452, 452 (2006) (explaining that the risk of SAI on stratospheric ozone "is likely to be small").

168. THE ROYAL SOCIETY, *supra* note 25, at 31 (describing aerosol's reflective properties).

169. *See* Wigley, *supra* note 167, at 452 (noting the contradictory and uncertain effects generated from computer models predicting the outcome of SAI SRM deployment).

170. *See* Vienna Convention, *supra* note 78, art. 2 (outlining the obligations of parties to CPOL).

171. *See* Montreal Protocol on Substances That Deplete the Ozone Layer art. 2.9, 2.10, Sept. 16, 1987, 1522 U.N.T.S. 3 (prohibiting certain substances due to their effect on stratospheric ozone).

172. *See* Justin McClellan et al., *Cost Analysis of Stratospheric Albedo Modification Delivery Systems*, 7 ENVTL. RESEARCH LETTERS 034019, 1 (2012) (estimating that full SAI SRM implementation would inject one to five teragrams of sulfur per year, which would be spread globally); S.J. Smith et al., *Anthropogenic Sulfur Dioxide Emissions: 1850–2005*, 11 ATMOSPHERIC CHEMISTRY & PHYSICS 1101, 1110 (2011) (placing actual global anthropogenic sulfur emissions at approximately fifty-eight teragrams per year, which are concentrated in North America and Europe).

In fact, it is possible to argue that the Vienna Convention favors climate engineering research. As noted above, climate change will impact the ozone layer.[173] Parties must "take appropriate measures . . . . to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer."[174] Climate engineering has the potential to reduce the adverse effects of climate change and secondarily may be able to reduce harm from stratospheric ozone depletion.[175] Specifically, the Vienna Convention commits Parties to undertake and cooperate in "research and scientific assessment on: The physical and chemical processes that may affect the ozone layer . . . [c]limatic effects deriving from any modifications of the ozone layer . . . [and] [s]ubstances, practices, processes and activities that may affect the ozone layer, and their cumulative effects."[176] In this context, sulfur dioxide is a substance and SAI SRM climate engineering is an activity that may affect the ozone layer and the climate. If there is a significant probability that SAI SRM might be deployed in the future, then research into the proposed techniques would improve understanding of its potential impact on stratospheric ozone.[177]

E. Convention on Long-Range Transboundary Air Pollution

The Convention on Long-Range Transboundary Air Pollution (LRTAP Convention) is a framework agreement, supplemented with protocols, which was developed under the auspices of the UN Economic Commission for Europe (UNECE) in order to reduce acid rain due to transboundary air pollution.[178] With respect to climate engineering in general, the LRTAP Convention encourages research.[179] Notably,

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173. *See* McKenzie, *supra* note 166, at 183 (describing the negative effects that climate change may have).

174. *See* Vienna Convention, *supra* note 78, art. 2.1 (obligating Parties to actively try and reduce the adverse effects of modifications to stratospheric ozone).

175. *See supra* notes 24–34 and accompanying text (describing the emergence of climate engineering).

176. *Id.* art. 3; *see also* art. 2.2(a), 4, Annex I (encouraging similar research to better understand the impact that human activities have on the ozone layer).

177. *See* THE ROYAL SOCIETY, *supra* note 25, at ix (advocating research into "whether low risk methods can be made available if it becomes necessary to reduce the rate of warming this century").

178. *See* LRTAP Convention, *supra* note 74, art. 2 (listing the fundamental principles of the LRTAP Convention). The United States, Canada, and the majority of European countries are Parties to the LRTAP Convention. *See* 1302 U.N.T.S. 217, n.1 (noting which countries have ratified the LRTAP Convention).

179. *See id.* art. 7 (advising parties to the convention to undertake research and development of existing and proposed technologies).

greenhouse gases and global warming likely qualify under the Convention as "long-range transboundary air pollution":

> "Air Pollution" means the introduction by man, directly or indirectly, of substances or energy into the air resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems and material property and impair or interfere with amenities and other legitimate uses of the environment . . . .[180]

This definition appears to require that "deleterious effects" have already occurred, which is arguably the case with climate change.[181] The "long-range transboundary" qualifier adds requirements for transboundary effects and for multiple individual sources that cannot readily be distinguished.[182] Given this, the LRTAP Convention can be seen as encouraging climate engineering research in three ways. First, it commits Parties to conduct and cooperate in research, including in the "economic, social and environmental assessment[s] of alternative measures for attaining environmental objectives including the reduction of long-range transboundary air pollution."[183] Climate engineering is an alternative measure for reducing global warming, which would likely be considered a long-range transboundary air pollutant.[184] Second, recalling that SRM is projected to have low financial costs, this technique should fall within the commitment that, "in order to combat air pollution [Parties are] to develop the best policies and strategies . . . in particular by using the best available technology which is economically feasible and low- and non-waste technology."[185] Third, in its 1994 Oslo Protocol,[186] "precautionary measures" are not only meant to "prevent or minimize emissions of air

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180. *Id.* art. 1; *see also* SANDS & PEEL, *supra* note 74, at 247 (discussing this definitional issue).

181. *See* LRTAP Convention, *supra* note 74, art. 5 ("Consultations shall be held . . . between, on the one hand, Contracting Parties which are actually affected by . . . long-range transboundary air pollution and, on the other hand, Contracting Parties within which and subject to whose jurisdiction a significant contribution to long-range transboundary air pollution originates . . . .").

182. *See id.* art. 1 (defining long-range transboundary air pollution).

183. *Id.* art. 7.

184. *See id.* art. 1 (defining "long-range transboundary air pollution" to include effects that "endanger human health, harm living resources and ecosystems").

185. *Id.*

186. Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on Further Reduction of Sulphur Emissions, June 13, 1994, 2030 U.N.T.S. 122 [hereinafter Oslo Protocol].

pollutants" but also to "mitigate their adverse effects" and "should be cost-effective."[187]

Field experiments of sulfur-based SAI SRM present a special case for the LRTAP Convention treaty regime, with the 1985 Helsinki,[188] 1994 Oslo, and 1999 Gothenburg Protocols being applicable.[189] Most importantly, the Gothenburg Protocol contains restrictions regarding "new stationary sources."[190] These new stationary sources must not exceed certain sulfur emission limits which vary by categories such as combustion plants and oil refineries.[191] Of course, it is possible that the Implementation Committee, which reviews compliance, and the governing Executive Body could exempt sulfur-based SAI SRM field tests from the Gothenburg Protocol restrictions because the production of acid rain within the covered UNECE region from this source of sulfur would be minimal due to the high emission altitude and subsequent atmospheric mixing.[192] Furthermore, there are a few exceptions to the sulfur emission limits for which the field tests might qualify.[193] Nevertheless, barring action by the LRTAP Convention

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187. *Id.* at pmbl. ¶¶ 3, 4.

188. Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on the Reduction of Sulphur Emissions or Their Transboundary Fluxes By at Least 30 Per Cent, July 8, 1985, 1480 U.N.T.S. 215 [hereinafter Helsinki Protocol].

189. Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-level Ozone, Nov. 30, 1999, 2319 U.N.T.S. 81 [hereinafter Gothenburg Protocol]. A handful of States, including some larger ones, are not parties to these protocols. Most importantly, the United States has not ratified the Oslo Protocol, nor has Russia. *See Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on Further Reduction of Sulphur Emissions*, UNITED NATIONS TREATY COLLECTION, https://treaties.un.org/pages/ViewDetails.aspx?sr c=TREATY&mtdsg_no=XXVII-1-e&chapter=27&lang=en (last visited May 7, 2014, 1:44 PM) (listing the countries that have ratified the Oslo Protocol). Canada has not ratified the Gothenburg Protocol, nor has Russia. *See* UNITED NATIONS TREATY COLLECTION, https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-1-h&chapter=27&lang=en (last visited May 7, 2014, 1:48 PM) (listing the parties that have ratified the Gothenberg Protocol).

190. *See* Gothenburg Protocol, *supra* note 189, art. 1 (defining new stationary sources).

191. *See id.* art. 3.2, Annex IV (establishing limits on sulfur emissions from stationary sources). New mobile sources are similarly regulated. *See id.* art. 3.5, Annex VIII (establishing limit values and "environmental specifications for marketed fuels for vehicles"). SAI tests do not seem to fall clearly into any particular category.

192. *See id.* art. 9 (discussing the powers of the Implementation Committee); *id.* art. 10 (requiring review of "data on the effects of concentrations and depositions of sulphur and nitrogen compounds and of photochemical pollution"); *see also* IPCC, PHYSICAL SCIENCE, *supra* note 1, FAQ 7.3 ("There has also been some concern that sulphate aerosol SRM would increase acid rain, but model studies suggest that acid rain is probably not a major concern since the rate of acid rain production from stratospheric aerosol SRM would be much smaller than values currently produced by pollution sources.").

193. *See* Gothenburg Protocol, *supra* note 189, Annex IV, tbl.1, n.a (providing a short list of exceptions to the limit values).

institutions and possible exceptions, these sulfur-based SAI SRM field tests appear to be prohibited in the Parties' territory by the Gothenburg Protocol.[194]

More generally, sulfur-based SAI SRM field experiments would be regulated as a contribution to each Party's total emissions.[195] For example, they would be subject to reporting requirements, which are disaggregated by source categories and approximate locations.[196] Further implications for sulfur-based SAI SRM field experiments would depend on their scale because, although sulfur-based SAI SRM would be a small contribution to global sulfur emissions, large experiments could greatly increase total emissions of individual countries.[197] At small scales, such field tests would be generally encouraged per the provisions cited above and by the Oslo Protocol's commitment for Parties to "encourage research, development, monitoring and cooperation related to . . . [t]he understanding of the wider effects of sulfur emissions on human health, the environment."[198] Field tests of sulfur-based SAI SRM large enough to significantly increase a country's total emissions may be prohibited by the softly-worded commitment in the LRTAP Convention that Parties are to "endeavor to limit and, as far as possible, gradually reduce and prevent air pollution"[199] and by the first

194. *See id.* art. 2 (stating the objectives of the Protocol, which include reducing sulfur emissions).

195. *See generally* LRTAP Convention, *supra* note 74 (addressing how Parties' emissions into the atmosphere are regulated).

196. *See id.* art. 8 (providing for an exchange of information for Parties to the agreement); Helsinki Protocol, *supra* note 188, art. 4 (requiring annual reporting of sulfur emission levels); Oslo Protocol, *supra* note 187, art. 5 (requiring periodic reporting of national annual sulfur emissions); Gothenburg Protocol, *supra* note 189, art. 7 (requiring periodic reporting of sulfur emissions). The Executive Body of the Convention determines the source categories, and the locations are in "grid-units of agreed size." *See* LRTAP Convention, *supra* note 74, art. 10 (establishing an "Executive Body" and defining the parameters of its authority).

197. *See* Gothenburg Protocol, *supra* note 189, Annex IV (establishing limit values for sulfur emissions from stationary sources). Assuming that a large-scale field test would be one-tenth the magnitude of deployment, and taking the midpoint of the estimated range for deployment, such a test could emit 0.3 teragrams of sulfur per year. *See* MacMynowski et al., *supra* note 54, at 5044 (calculating to what extent uncertainty could be reduced through an SRM field test of one-tenth of the deployment intensity needed to counteract the warming from a doubling of atmospheric carbon dioxide concentration); McClellan et al., *supra* note 172, § 2.1 (estimating the amount of sulfur needed for SAI SRM deployment). This would be 1.5 times the current sulfur emissions of the United Kingdom or Germany. *See* EUROPEAN ENVT. AGENCY, EUROPEAN UNION EMISSION INVENTORY REPORT 1990–2010 UNDER THE UNECE CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION 52–54 (2012) (discussing current sulfur emissions of European countries).

198. Oslo Protocol, *supra* note 187, art. 6; *see also supra* notes 182–191 and accompanying text.

199. LRTAP Convention, *supra* note 74, art. 2.

obligation of the Oslo Protocol that its Parties "shall control and reduce their sulfur emissions."[200] These tests would furthermore be contrary to the objective of the Gothenburg Protocol.[201] In reality, Parties sometimes do have significant increases in their total emissions while remaining below their emission reduction commitments.[202] The Implementation Committee, however, has apparently not addressed these significant below-limit increases in its reports to the Executive Body.[203] Such a below-limit increase would most likely be judged by the other Parties and the Implementation Committee in its full context, including whether high-altitude sulfate emissions from tests would be deposited within the Parties' territory or, alternatively, would be diluted and deposited over a much larger area.[204] If field tests would be "a significant contribution to long-range transboundary air pollution," then a potentially affected state could request consultations with the source state.[205] Field tests of sulfur-based SAI SRM that would cause a Party to the Oslo or Gothenburg Protocols to exceed its sulfur emissions limit would be prohibited.[206]

F. Outer Space Treaty

The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other

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200. Oslo Protocol, *supra* note 187, art. 2.1; *see also* arts. 2.4, 4.1(b) (discussing the commitments to reduce emissions).

201. *See* Gothenburg Protocol, *supra* note 189, art. 2.1 (stating the Protocol's objective to reduce sulfur emissions).

202. *See* European Environment Agency, *supra* note 197, at 11–12 (discussing siginificant emissions increases from 1990 to 2010); Oslo Protocol, *supra* note 187, Annex II (creating sulfur ceilings but not addressing significant below-limit increases); Gothenburg Protocol, *supra* note 189, Annex II (establishing sulfur ceilings but, again, not addressing significant below-limit increases).

203. *See, e.g.*, Fifteenth Report of the Implementation Committee to the Executive Body for the Convention on Long-range Transboundary Air Pollution, 31st Sess., Dec. 11–13, 2012, ECE/EB.AIR/2012/16 (reporting on the implementation of the LRTAP Convention) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

204. *See generally* LRTAP Convention, *supra* note 74 (establishing parameters for evaluating increases in sulfur emissions).

205. *See id.* art. 5 (requiring consultations "upon request, at an early stage, between, . . . Parties which are actually affected by or exposed to a significant risk of long-range transboundary air pollution and, on the other hand, Contracting Parties within which . . . long-range transboundary air pollution originates").

206. *See* Oslo Protocol, *supra* note 187, Annex II (providing limits for sulfur emissions); Gothenburg Protocol, *supra* note 189, Annex II (providing new limits for sulfur emissions as of 1999). For example, Germany and the United Kingdom could presently perform experiments where they emit up to one sixth and one third of their allotted sulfur emissions respectively. *See supra* note 197 and accompanying text.

Celestial Bodies (the Outer Space Treaty) is the most important international instrument in space law.[207] All nations that have a space program are Parties to the Outer Space Treaty.[208] Proposals to place objects in space, either in Earth or solar orbit, have long been considered potential SRM methods, in part because they could be very effective and would not interfere directly in ecosystems, even though they are consistently assessed as economically infeasible.[209] Evaluating the role of international law for space-based climate engineering research is complicated by the fact that, to a greater degree than other suggested methods, there could be little distinction between field research and deployment.

In general, the Outer Space Treaty and related agreements permit research on space-based SRM methods by, for example, establishing "freedom of scientific investigation in outer space," and committing States to cooperate therein.[210] Parties are to conduct space activities "for the benefit and in the interests of all countries"[211] and "with due regard to the corresponding interests of all other States Parties."[212] A subsequent UN General Assembly resolution addressed this potentially unclear passage, indicating that it is intended to encourage consideration of developing countries' needs and to stimulate voluntary cooperation, and not to imply veto rights on other countries' activities in space.[213] The Outer Space Treaty

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207. *See generally* Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, Dec. 19, 1966, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty]; THE UNITED NATIONS AT WORK 41 (Martin Ira Glassner ed., 1998) ("The most important of the UN space law instrumetns has been the [Outer Space Treaty] . . . .").

208. *See Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*, UNITED NATIONS TREATY COLLECTION, https://treaties.un.org/pages/showDetails.aspx?objid=0800000280128cbd (last visited May 7, 2014, 2:12 PM) (listing parties to the Outer Space Treaty) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

209. *See* THE ROYAL SOCIETY, *supra* note 25, at 32–34 (explaining that light refraction from space could be a possible SRM method, however, it would be prohibitively expensive).

210. *See* Outer Space Treaty, *supra* note 207, art. I ("There shall be freedom of scientific investigation in outer space, including the Moon and other celestial bodies, and States shall facilitate and encourage international cooperation in such investigation.").

211. *Id.* art. I.

212. *Id.* art. IX.

213. *See generally* Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries, G.A. Res. 122, U.N. GAOR, 51st Sess., Supp. No. 49, at 114, U.N. Doc. A/RES/51/122 (Dec. 13, 1966) (addressing the obligations and powers of States with space programs and States without space programs under the Outer Space Treaty); *see also* FRANCIS LYALL & PAUL B. LARSEN, SPACE LAW: A TREATISE, 63–65 (2009) (explaining the prevailing desire, particularly among countries with space programs,

requires communication, that is, to inform the UN, the scientific community, and the public about relevant activities.[214] Finally, other international laws, including the customary law regarding transboundary harm, also apply in space.[215]

The most detailed applicable provisions under space law are those regarding liability, which could present a disincentive toward researching space-based SRM.[216] The Outer Space Treaty and the Convention on International Liability for Damage Caused by Space Objects hold Parties responsible for their space-based activities and absolutely liable for damage caused by launched objects.[217] This liability is not restricted to accidents, malfunctions, or to damage from direct contact with launched objects, but instead includes damage from objects that remain in orbit and continue to function as intended.[218] Because the definition of "damage" is limited to that occurring to persons and property, recoverable damage to the environment would include only its economic value possessed by natural or legal persons.[219] The agreements, however, are silent on how direct the causation must be.[220] Scholars generally agree that indirect and nonphysical damage is covered, but have divergent opinions regarding how direct the

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that the benefit and interests be "met simply by the activities being beneficial in a generalised way").

214. *See* Outer Space Treaty, *supra* note 207, art. XI (instituting a requirement that signatory Parties report to the UN Secretary General, and inform the public and scientific community of the nature of their interstellar activities).

215. *See id.* art. III (placing the Outer Space Treaty under the purview of international law).

216. *See id.* art. VII (establishing liability for any state that launches objects into space).

217. *See* Convention on International Liability for Damage Caused by Space Objects, pt. B, art. II, Nov. 29, 1971, 961 U.N.T.S. 187 [hereinafter Space Liability Convention] (creating absolute liability for damage to the surface of Earth or to aircraft).

218. *See* Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, princ. 8, G.A. Res. 1962, U.N. GAOR 18th Sess., Supp. No. 15, at 15, U.N. Doc. A/RES/18/1962 (Dec. 13, 1963) ("[E]ach State from whose territory or facility an object is launched, is internationally liable for damage to a foreign State or to its natural or juridical persons by such object or its component parts on the Earth, in air space, or in outer space."). The Outer Space Treaty and the Space Liability Convention make no reference to accidents or malfunctions nor to direct physical contact, but States are "internationally liable for damage to a foreign State or to its natural or juridical persons by such object or its component parts on the Earth, in air space, or in outer space." *Id.* ¶ 8.

219. *See* Space Liability Convention, *supra* note 217, art. I(a) ("The term 'damage' means loss of life, personal injury or other impairment of health; or loss of or damage to property of States or of persons, natural or juridical, or property of international intergovernmental organizations."); *see also* LOTTA VIIKARI, THE ENVIRONMENTAL ELEMENT IN SPACE LAW: ASSESSING THE PRESENT AND CHARTING THE FUTURE 68–69 (2008) (discussing the scope of liability created under the Space Liability Convention).

220. *See, e.g.*, Space Liability Convention, *supra* note 217, art. XII (invoking "international law and the principles of justice and equity," and implying inclusion of indirectly-caused and delayed damages).

causation must be.[221] This disagreement is further complicated by the fact that proving causation in a dispute over the effects of space-based SRM testing or deployment would be very difficult. It is important to note that the Space Liability Convention has an article concerning catastrophic risks from space objects that requires the responsible state to "examine the possibility of rendering appropriate and rapid assistance."[222]

G. United Nations Convention on the Law of the Sea

The UN Convention on the Law of the Sea (UNCLOS) is a comprehensive international agreement describing the rights and duties of States in their marine activities, including the protection of the marine environment and the conduct of marine scientific research.[223] Some proposed climate engineering methods and their field research would occur in or over the ocean, such as ocean fertilization, MCB, and (possibly) SAI.[224] UNCLOS also applies to land-based activities that affect the marine environment.[225] States under UNCLOS have rights and obligations that will impact climate engineering field experiments in a complex manner.[226]

The desire to protect the marine environment is evident throughout UNCLOS, under which "States have the obligation to protect and preserve the marine environment."[227] This is without qualification and exception. Furthermore, Parties have obligations "to take . . . such measures . . . for the living resources of the high seas . . . to prevent, reduce and control pollution

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221. *Compare* W.F. Foster, *The Convention on International Liability for Damage Caused by Space Objects*, 10 CAN. YEARBOOK INT'L L. 137, 158 (1972) (discussing liability for damages caused by space objects), *with* Carl Q. Christol, *International Liability for Damage Caused by Space Objects*, 74 AM. J. INT'L L. 346, 358–62 (1980) (reviewing various interpretations of the Treaty). Scholars generally agree that indirect and nonphysical damage is covered, however. *See* Foster, *supra*, at 155 ("Moreover, it is immaterial whether the injuries are suffered through physical impact . . . ."); Christol, *supra*, at 362 ("[I]t may be anticipated that the convention will be interpreted as covering both direct and indirect damage . . . .").

222. *See* Space Liability Convention, *supra* note 217, art. XXI (establishing state responsibility for catastrophic injury).

223. *See generally* UNCLOS, *supra* note 73 (setting out the rights and obligations of any state that engages activities on the seas).

224. *See supra* notes 23–45 and accompanying text (providing an overview of such methods).

225. *See* UNCLOS, *supra* note 73, art. 207 ("States shall adopt laws and regulations to prevent, reduce and control pollution of the marine environment from land-based sources . . . .").

226. *See generally id.* (discussing, at length, the rights and obligations of States with respect to the seas).

227. *Id.* art. 192.

of the marine environment from any source . . . .";[228] to ensure "that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other States and their environment, and that pollution arising from incidents or activities under their jurisdiction or control does not spread beyond the areas where they exercise sovereign rights . . . ."[229]; and to "take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control . . . ."[230] The States are also required to assess and to communicate the expected effects of "substantial pollution of or significant and harmful changes to the marine environment" caused by activities under their control.[231] Importantly, "pollution of the marine environment" is defined, as in the LRTAP Convention, to include "the introduction by man, directly or indirectly, of substances or energy into the marine environment,"[232] but in this case with a lower threshold of certainty.[233] This definition includes greenhouse gases and probably global warming.[234] Under UNCLOS, pollution is not limited to marine-based sources, although the pollution must enter the marine environment.[235] Furthermore, States are to prevent marine pollution "from any source" including "from land-based sources [or] from or through the atmosphere."[236] Not only will climate change warm the ocean, but elevated atmospheric carbon dioxide concentrations will also acidify it, and both processes will have deleterious effects.[237] These effects imply a need to balance the risks to the marine environment from climate engineering research with those from climate change. UNCLOS, however, provides that "States shall act so as not to transfer, directly or indirectly, damage or hazards from one area to another or transform one type of pollution into

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228. *Id.* art. 117.
229. *Id.* art. 194.
230. *Id.* art. 196.
231. *See id.* arts. 204–06 (discussing monitoring and assessing effects on the marine environment).
232. *Id.* art. 1.1(4).
233. *See supra* note 180 and accompanying text (providing the LRTAP Convention definition).
234. *See* UNCLOS, *supra* note 73, art. 1 (including "deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, . . . impairment of quality for use of sea water and reduction of amenities" in the definition of pollution to the marine environment).
235. *See id.* art. 204 ("States shall . . . observe, measure, evaluate and analyse, by recognized scientific methods, the risks or effects of pollution of the marine environment.").
236. *Id.* art. 194.
237. *See* IPCC, IMPACTS, *supra* note 16, § 6 ("Climate change alters physical, chemical, and biological properties of the ocean . . . Impacts of ocean acidification range from changes in organismal physiology and behavior to population dynamics . . . . and will affect marine ecosystems for centuries if emissions continue.").

another."[238] Scholars dispute this article's impact on climate engineering.[239] Regardless of its impact, research projects of limited scale would not have the intention of transferring hazards, but of learning whether climate engineering deployment would have deleterious effects on the environment and whether it would indeed transfer hazards.[240]

UNCLOS is generally supportive of scientific research at sea.[241] Although "marine scientific research" remains undefined under UNCLOS, the various definitions considered during negotiations and proposed after the text was finalized all included the research of climate engineering techniques, which intervene in the ocean, and likely also those that operate in the atmosphere above the ocean.[242] For example, one of the last proposed

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238. UNCLOS, *supra* note 73, art. 195.

239. *Compare* Philomene Verlaan, *Geo-Engineering, the Law of the Sea, and Climate Change*, 2009 CARBON & CLIMATE L. REV. 446, 457–58 (2009) (arguing that climate engineering projects would likely violate article 195, and that the burden is on the projects' proponents to demonstrate that it would not), *with* James Edward Peterson, *Can Algae Save Civilization: A Look at Technology, Law, and Policy Regarding Iron Fertilization of the Ocean to Counteract the Greenhouse Effect*, 6 COLO. J. INT'L ENVTL. L. & POL'Y 61, 92 (1995) (asserting that article 195 would apply only if the intervention ocean fertilization were to be shown to have harmful environmental effects).

240. *See* THE ROYAL SOCIETY, *supra* note 25, at ix (stating that one purpose of research is to avoid "methods which involve activities or effects that extend beyond national boundaries"); *but see* GREGOR BETZ ET AL., LARGE SCALE INTENTIONAL INTERVENTIONS INTO THE CLIMATE SYSTEM?: ASSESSING THE CLIMATE ENGINEERING DEBATE 31 (Wilfried Rickels et al. eds., 2011), *available at* http://www.fona.de/mediathek/pdf/Climate_Engineering_engl.pdf ("By carrying out research into and planning for climate engineering, one passes on risks that arise today to future generations.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

241. *See* UNCLOS, *supra* note 73, pmbl. ¶ 4, arts. 87.1, 88, 238–239, 243, 251, 255, 257 (recognizing the importance of supporting research at sea).

242. *See* UNITED NATIONS DIVISION FOR OCEAN AFFAIRS AND THE LAW OF THE SEA, OFFICE OF LEGAL AFFAIRS, THE LAW OF THE SEA: MARINE SCIENTIFIC RESEARCH: A REVISED GUIDE TO THE IMPLEMENTATION OF THE RELEVANT PROVISIONS OF THE UNITED NATIONS CONVENTION ON THE LAW OF THE SEA 4–6 (2010) (reviewing definitions of marine scientific research which were considered during drafting); *see also* GEORGE K. WALKER, DEFINITIONS FOR THE LAW OF THE SEA: TERMS NOT DEFINED BY THE 1982 CONVENTION 241–44 (2011) (discussing the meanings of marine scientific research). Whether research is conducted in, on, or above the high seas does not matter; although it is unclear under UNCLOS whether research conducted in the atmosphere above a nation's exclusive economic zone and continental shelves is considered marine research. *See* FLORIAN H. TH. WEGELEIN, MARINE SCIENTIFIC RESEARCH: THE OPERATION AND STATUS OF RESEARCH VESSELS AND OTHER PLATFORMS IN INTERNATIONAL LAW 251–255 (2005) (discussing the legal regime of air space located over the high seas, contiguous zones, and exclusive economic zones). The most relevant question, however, is whether climate engineering research would increase knowledge of the "marine environment," a phrase that is undefined but generally interpreted to include the marine atmosphere. *See* ALFRED H.A. SOONS, MARINE SCIENTIFIC RESEARCH AND THE LAW OF THE SEA 124 (1982) (analyzing the meaning of "marine scientific

definitions to be included in a negotiating text was "any study or related experimental work designed to increase man's knowledge of the marine environment."[243] Parties commit to promote marine scientific research and to create favorable conditions for it, as well as to promote cooperation and communication in research.[244] It must be conducted "using appropriate scientific methods and means," for peaceful purposes, in a manner consistent with other international law, and in a manner that does not "unjustifiably interfere with other legitimate uses of the sea."[245] Most pertinently, Parties' right to research is subject to their obligation to protect the marine environment.[246] States and sponsoring international organizations may be held liable for damage caused by pollution due to research or by actions in contravention of the agreement.[247]

Some of the rights and obligations concerning marine scientific research vary by the location of the proposed activity.[248] Within territorial waters,[249] coastal States "have the exclusive right to regulate, authorize and conduct marine scientific research," and research therein requires their express consent.[250] In the exclusive economic zones and continental shelves, coastal States have a similar right, but they are to grant consent "in

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research"); *see also* VERONICA FRANK, THE EUROPEAN COMMUNITY AND MARINE ENVIRONMENTAL PROTECTION IN THE INTERNATIONAL LAW OF THE SEA: IMPLEMENTING GLOBAL OBLIGATIONS AT THE REGIONAL LEVEL 12 (2007) (discussing the lack of definition for "marine environment"). Regardless, considering the expected impact of climate change and climate engineering on the ocean, atmospheric climate engineering research would qualify as marine scientific research. *See* Karen N. Scott, *Regulating Ocean Fertilization Under International Law: The Risks*, CARBON AND CLIMATE L. REV. 108, 109–10 (2013) (describing the impacts of climate change and fertilization on the ocean).

243. Informal Single Negotiating Text, Third United Nations Conference on the Law of the Sea, Part III, Part II, art. 1, U.N. Doc. A/CONF.62/WP.8/Part III (1982).

244. *See* UNCLOS, *supra* note 73, arts. 239, 242–44, 250 (providing that States shall promote and facilitate marine scientific research in accordance with the Convention).

245. *Id.* art. 240 (providing general principles for scientific research).

246. *See id.* arts. 192, 238 (discussing States' general obligation to protect the marine environment and States' rights to conduct scientific research).

247. *See id.* art. 263 ("States . . . shall be responsible and liable for the measures they take in contravention of this Convention . . . . States . . . shall be responsible and liable pursuant to article 235 for damage caused by pollution of the marine environment arising out of marine scientific research undertaken by them or on their behalf."). If a climate engineering research activity were to be considered "pollution of the marine environment" instead of "marine scientific research," liability would be independent of any violation of law. *See id.* art. 235 ("[States] shall be liable in accordance with international law.").

248. *See id.* arts. 245–46 (explaining scientific research rights available in the territorial sea, the exclusive economic zone, and the continental shelf).

249. *See id.* art. 2 ("The sovereignty of a coastal State extends . . . to an adjacent belt of sea, described as the territorial sea.").

250. *See id.* art. 245 (providing guidelines for marine scientific research in a States' territorial sea).

normal circumstances" to researching States and "competent international organizations."[251] There, the coastal State must exercise this and other rights with due regard for other States, and the researching State must have due regard for the coastal State and comply with the coastal State's laws and regulations.[252] On the high seas, States and international organizations have the right to conduct research, but this must be performed with due regard for other States.[253] Research conducted within the "Area"[254] is subject to additional requirements, particularly that it is "for the common benefit of mankind as a whole" and that results are shared.[255]

A special note must be made of ocean fertilization and its research, which may or may not qualify as "dumping." As defined in UNCLOS, "dumping," in part, is "any deliberate disposal of wastes or other matter . . . at sea," but excludes "placement of matter for a purpose other than the mere disposal thereof."[256] UNCLOS Parties have committed to prevent, reduce, and control pollution of the sea by dumping.[257] Coastal States have the right to permit, regulate, and control dumping within their territorial waters, exclusive economic zones, and continental shelf, but must consider how other States may be impacted.[258] Parties are to establish global rules regarding dumping, and their national laws must be no less effective than these global rules.[259]

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251. *See id.* art. 246 (providing guidelines for marine scientific research in the exclusive economic zone and the continental shelf). UNCLOS details circumstances under which coastal States may withhold their consent, as well as the duties of the States and international organizations who conduct such research. *See id.* arts. 246–49, 252–54 (detailing state and researchers' rights and obligations concerning marine environmental research).

252. *See id.* arts. 56, 58 (discussing the rights and duties of various States within the exclusive economic zone).

253. *See id.* arts. 87, 257 (providing for the freedom to research on the high seas and the right to perform research beyond exclusive economic zones).

254. *See id.* art. 1 ("'Area' means the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction.").

255. *See id.* art. 143 (covering permissible marine scientific research in the Area).

256. *Id.* art. 1.1(5).

257. *See id.* arts. 194.3(a), 210 (requiring States to take measures against pollution of the marine environment, including dumping).

258. *See id.* art. 210.5 (providing guidelines for dumping in certain areas). Dumping by other States in these areas requires permission from the coastal state. *See id.* ("Dumping within the territorial sea and the exclusive economic zone or onto the continental shelf shall not be carried out without the express prior approval of the coastal State . . . .").

259. *See id.* arts. 210.4, 210.6 (discussing the establishment and effectiveness of Parties' global, regional, and national rules concerning pollution).

H. London Convention and London Protocol

The London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and its London Protocol (together, the LC-LP) are two MEAs that regulate dumping at sea.[260] The former has eighty-seven parties, whereas the latter—intended to replace the former—currently has forty-two parties.[261] These MEAs use essentially the same definition for "dumping" as UNCLOS; thus, ocean fertilization could potentially be classified under these MEAs as dumping.[262] In response to a private company that intended to conduct field experiments using a flag of convenience and a negative assessment of ocean fertilization in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, the Contracting Parties to the LC-LP took up the issue and began to develop a nonbinding regulatory framework for ocean fertilization.[263]

The regulatory framework adopted by the LC-LP Parties rests upon two new definitions provided in their 2008 decision. First, "ocean fertilization is any activity . . . with the principle intention of stimulating primary productivity in the oceans [excluding] conventional aquaculture, or

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260. *See generally* Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter art. I, Nov. 13, 1972, 1046 U.N.T.S. 120 [hereinafter London Convention] (providing the terms of the London Convention, requiring States to prevent pollution of the sea caused by dumping); Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 art. 3.4, Nov. 7, 1996, 11 U.K.T.S. Cm. 4078 [hereinafter London Protocol] (adopting stricter measures for preventing dumping).

261. *See* Office for the London Convention and Protocol, *London Convention and Protocol*, INTERNATIONAL MARITIME ORGANIZATION, http://www.imo.org/blast/mainframemenu.asp?topic_id=1488 (last visited Jan. 8, 2014) (listing signatories) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

262. *Compare* UNCLOS, *supra* note 73, art 1.1(5) (defining "dumping"), *with* London Convention, *supra* note 260, art. III.1 (defining actions that "dumping" does and does not include), *and* London Protocol, *supra* note 260, art. 1.4 (same). The two definitions differ in ways that are not relevant to this paper, but the London Convention preceded UNCLOS and is thus the origin of the definition.

263. Russ George, the CEO of Planktos, Inc. threatened to use a flag of convenience after the Environmental Protection Agency, which is responsible for implementing the London Convention in the United States, sent a letter to the company. *See* United States, Planktos, Inc., Large-scale Ocean Iron Addition Projects, I.M.O. Doc. LC/SG 30/INF.28 (June 1, 2007) (discussing Planktos Inc.'s dispute with the EPA over ocean iron addition projects); Report of the Thirtieth Meeting of the Scientific Group of the London Convention and the First Meeting of the Scientific Group of the London Protocol, ¶ 2.22, I.M.O. Doc. LC/SG 31/16 (July 25, 2007) (reporting on the decision-making process of the LC-LP in its regulation of ocean fertilization); *see also* Resolution LC-LP.1 on the Regulation of Ocean Fertilization pmbl. ¶ 3, I.M.O. Doc. LC 10/16/Annex 6 (Oct. 31, 2008) [hereinafter LC-LP.1] (noting that States are encouraged to study and understand ocean iron fertilization).

mariculture, or the creation of artificial reefs."[264] The Parties decided that ocean fertilization indeed falls within the scope of the LC-LP and that it, in general, should not be allowed.[265] An exception to this prohibition was made for the second new definition, "legitimate scientific research."[266] Distinguishing legitimate scientific research from illegitimate ocean fertilization requires an assessment framework, described in the Parties' 2010 decision.[267] Under this framework, researchers apply to the appropriate regulatory agency of their home state for approval to conduct scientific research.[268]

The assessment consists of two stages. The first is an initial review to determine whether the proposal is, in fact, a scientific one that would be subject to peer review and would not result in financial gain for the researchers.[269] The second is a more elaborate environmental assessment, which includes, among other things, an assessment of exposure effects, risk characterization, and risk management.[270] Notably, the risk management procedures should be based on a "precautionary approach," and the decision whether to reject the proposal or to ask for revisions should take into account this precautionary approach.[271] During the second phase, the researching Party is also to notify potentially affected countries, and to

264. LC-LP.1, *supra* note 263, ¶ 2 n.3. Primary production is the creation of organic matter from carbon dioxide, usually through photosynthesis. *See* THE ROYAL SOCIETY, *supra* note 25, at 79 (defining primary production as "[a]ll forms of production accomplished by plants").

265. *See* LC-LP.1, *supra* note 263, ¶ 8 ("[O]cean fertilization activities other than legitimate scientific research should not be allowed.").

266. *See id.* ¶ 3 (providing an exception for placement of matter for research purposes).

267. *See* Resolution LC-LP.2 on the Assessment Framework for Scientific Research Involving Ocean Fertilization, I.M.O. Doc. LC 32/15/Annex 6 (Oct. 14, 2010) (adopting a framework to guide case-by-case assessment of research proposals).

268. *See id*. (determining what constitutes scientific research under the London Convention and Protocol); *see also* Assessment Framework for Scientific Research Involving Ocean Fertilization § 1, in Report of the Thirty-Second Consultative Meeting and the Fifth Meeting of Contracting Parties, I.M.O. Doc. LC 32/13/Annex 6 (Oct. 14, 2012) [hereinafter Assessment Framework] (providing a framework for assessing ocean fertilization research proposals).

269. *See* Assessment Framework, *supra* note 268, § 2 (detailing the initial assessment process).

270. *See id*. § 3 (discussing the environmental assessment process).

271. *See id.* §§ 1.3.2.6, 4.3 (explaining that risk management procedures are precautionary and that the decision to reject a proposal should take a precautionary approach into account). The precautionary principle presumably refers to that of the London Protocol: "it is important that States use the best practicable means to prevent such [marine] pollution." London Protocol, *supra* note 260, pmbl. ¶ 5.

consult with stakeholders.[272] If the project is approved, reports on the impacts during a field experiment are to be regularly sent to the Secretariat, and information from these reports can provide the basis to modify or to revoke the authorization as well as to improve future decision-making.[273]

The LC-LP decisions have already come under challenge.[274] In 2012, a private company conducted a large ocean fertilization experiment without the approval of its home state, Canada.[275] The company's representatives claimed that their intention was to increase salmon stocks on behalf of a Native American village, thus potentially avoiding the definition of ocean fertilization in the 2010 regulatory framework.[276] After this work was revealed, the Canadian government announced an investigation into the ocean fertilization and the LC-LP Contracting Parties issued a statement deeming this project to be ocean fertilization.[277]

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272. *See* Resolution LC-LP.2 on the Assessment Framework for Scientific Research Involving Ocean Fertilization, *supra* note 268, § 1.8 (imposing consultation and notice requirements on stakeholders).

273. *See id.* §§ 5.1–5.2 (mandating s reports on the impacts of ocean fertilization for the Secretariat and noting that the information from these reports must inform and improve future decisionmaking).

274. *See* Craik et al., *supra* note 94, at 120–21 (discussing inter alia recent ocean fertilization activities which did not conform with LC-LP regulations).

275. *See id.* at 117–18 (summarizing the company's activities and claims).

276. *See id.* ("The principals involved in the activity characterized it as an ocean 'restoration' project, aimed at enhancing decreasing salmon stocks. However, they also made public statements indicating that they planned . . . to sell carbon credits on international markets for the carbon dioxide they assumed would be sequestered by the project."). Stimulating primary production could be a means to achieve the goal of salmon restoration or carbon sequestration. The issue thus appears to be the precise meaning of "principle intention." *See id.* at 122 (explaining that the principle intention of the experiment was to enhance salmon stocks). To further complicate matters, the president of the fertilization company, John Disney, claims that the boat was flying the village flag—implying the absence of a Canadian flag—and that the experiment occurred beyond 200 miles from shore (beyond Canada's exclusive economic zone) but within the marine territory of the village, "which goes out to wherever they perceive the line to be based on where they sit now in the legal world, which is under aboriginal rights and title." *See West Coast Ocean Fertilization Project Defended*, CBC NEWS (Oct. 19, 2012), http://www.cbc.ca/news/technology/story/2012/10/19/bc-ocean-fertilization-haida.html (reporting the location of the experiment and that it was purportedly within the marine territory of a native village) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

277. *See Company Behind Ocean Fertilization Experiment Loses Court Bid to Block Charges*, THE CANADIAN PRESS (Feb. 4, 2014), http://www.cntvna.com/News/2014-02/04/cms133257article.shtml ("The organization behind a controversial ocean fertilization experiment off the coast of British Columbia faces potentially 10 charges for environmental violations after losing a court bid that would have brought an end to the investigation [by the Canadian government].") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); Report of the Thirty-Fourth Consultative Meeting of the Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of

In 2013, the Parties to the London Protocol (but not those to the London Convention) approved an amendment to the London Protocol, which, once accepted by two-thirds of the Parties, would implement a broader and binding regulatory framework.[278] The amendment specifically defines "marine geoengineering," which is not limited to ocean fertilization, scientific research, or a particular goal:

> "Marine geoengineering" means a deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts, and that has the potential to result in deleterious effects, especially where those effects may be widespread, long lasting or severe.[279]

The marine geoengineering activities listed in an accompanying proposed annex are either prohibited outright or would require a permit from a Party's administrative government.[280] For those activities which are listed and do require a permit, Parties are to follow a general assessment framework provided in a second proposed annex, as well as any other assessment mechanism developed by the Parties for a specific activity.[281] The general assessment framework for marine geoengineering activities calls for a detailed description of the proposed activity, notification of "potentially affected countries and relevant regional intergovernmental agreements and arrangements," and a consultation plan.[282] Parties are obligated to carry out a consultation process during the assessment phase, and "[c]onsent should be sought from all countries with jurisdiction or interests in the region of potential impact."[283] Both the Party responsible for

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Wastes and Other Matter, 1972, and Seventh Meeting of Contracting Parties to the 1996 Protocol thereto, Doc. LC 34/15, Nov. 23, 2012, Annex 3 (expressing "grave concern" at the ocean fertilization activity that took place in the Pacific Ocean off of the coast of Canada).

278. *See* Res. LP.4(8) on the Amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities, Oct. 18, 2013, Rep. of the Thirty-Fifth Consultative Meeting and the Eighth Meeting of Contracting Parties, Doc. LC 35/15, Annex 4 (Oct. 21, 2013) (adopting an amendment to the London Protocol to regulate marine geoengineering).

279. *Id.* Annex 4, art.1.

280. *See id.* Annex 4 (stating that Parties shall not allow listed marine geoengineering activities unless the activity may be authorized by permit).

281. *See id.* Annex 5 (imposing requirements on assessment frameworks).

282. *Id.* Annex 5, ¶ 10 ("[P]otentially affected countries and relevant regional intergovernmental agreements and arrangements should be identified and notified and a plan should be developed for ongoing consultations on the potential impacts, and to encourage scientific cooperation.").

283. *Id.* Annex 5, ¶ 11.

the regulation as well as any potentially affected countries should seek expert advice, including peer review.[284] The ultimate assessment under the general framework is to be based on the site, the matter to be placed in the ocean, its expected effects, the proposed risk management, the means of monitoring, the financial resources available, consultation requirements, the environmental impact, and the expected benefits.[285] Regarding the last two criteria, the framework implicitly acknowledges the climate change/climate engineering tension, in that it calls for "conditions [to be] in place to ensure that, as far as practicable, environmental disturbance and detriment would be minimized and the benefits maximized."[286] The proposed general assessment framework also details considerations which must be met in order for an activity to be "a specific marine scientific research activity," a subset of the more general "marine geoengineering activities" category.[287] These requirements include: contributing to scientific knowledge, using appropriate methodology, being subject to peer review, a commitment to open publication of results, and a lack of personal economic interests.[288] As it is presently proposed, ocean fertilization is the only marine geoengineering activity listed in the annex, which requires a permit and is limited only to legitimate scientific research.[289]

I. Antarctic Treaty System

The Antarctic Treaty System governs relations among countries in the area beyond sixty degrees latitude south, where some of the proposed climate engineering methods, particularly ocean fertilization and SAI, could be researched.[290] Relevant here is the Antarctic Treaty and its Madrid Protocol on Environmental Protection.[291] Like UNCLOS, the Antarctic

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284. *See id.* Annex 5, ¶ 12 (stating that contracting Parties should consider advice for proposals from international experts, and that advice should include peer review as necessary).

285. *See id.* Annex 5, ¶¶ 8–9 (detailing information required for assessment of a proposal).

286. *Id.* Annex 5, ¶ 26.5.

287. *Id.* Annex 5, ¶¶ 7–9.

288. *See id.* Annex 5, ¶ 8 (listing considerations that must be applied to determine whether specific marine scientific research activity will be permitted).

289. *See id.* Annex 5, ¶ 1 (stating that an ocean fertilization activity will not be given a permit unless it constitutes legitimate scientific research).

290. *See* Antarctic Treaty, *supra* note 88, art. VI (stating that the provisions of the treaty cover the "area south of 60° South Latitude").

291. *See id.* arts. II–III (promoting, among other things, cooperation in scientific investigation in Antarctica); Madrid Protocol, *supra* note 79, art. 3 (seeking to limit adverse environmental impacts on Antarctica and acknowledging that the continent presents opportunities for scientific discovery). Both the Antarctic Treaty and the Madrid Protocol have been adopted by all countries with Antarctic activity. *Id.*

Treaty system calls for both environmental protection and scientific research.[292] In particular, the brief Treaty establishes a "freedom of scientific investigation," within which Parties are to cooperate and share information.[293] It also calls for the Parties to meet to discuss and further the facilitation of scientific research, as well as the "preservation and conservation of living resources."[294] The Madrid Protocol is more detailed about both environmental protection and scientific research.[295] Generally speaking, it promotes both, often simultaneously.[296] For example, the objective of the Parties is to protect the Antarctic environment and to designate the area as "a natural reserve, devoted to peace and science."[297] Similarly, the agreement's first principle is that both environmental protection and Antarctica's "value as an area for the conduct of scientific research, in particular research essential to understanding the global environment, shall be fundamental considerations in the planning and conduct of all activities."[298] One principle states that "[a]ctivities shall be planned and conducted so as to accord priority to scientific research . . . including research essential to understanding the global environment,"[299] while the following principle states that activities shall be "modified, suspended or cancelled if they result in or threaten to result in impacts upon the Antarctic environment."[300]

The Madrid Protocol and its Annexes impose obligations on its Parties that could apply in the context of climate engineering field research. All activities must be for peaceful purposes.[301] Further, the climate

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292. *See* Antarctic Treaty, *supra* note 88, art. IX.1 (explaining that among the objectives of the treaty are facilitation of scientific research and preservation of resources in Antarctica). Interestingly, "scientific research" is left undefined.

293. *See id.* arts. II ("Freedom of scientific investigation in Antartica and cooperation toward that end . . . shall continue . . . .").

294. *See id.* art. IX.1 (stating that the Parties shall meet and consult with each other regarding measures which can help to use Antarctica for peaceful purposes, to facilitate scientific research, and to preserve living resources).

295. *See* Madrid Protocol, *supra* note 80, art. 3 (describing the activities that must be planned to limit adverse impacts to the Antarctic environment, giving a list of adverse effects to avoid, and also explaining that the value of scientific research will be considered and weighed based on a comprehensive list of factors).

296. Notably, earlier drafts placed a greater emphasis on scientific research, with environmental protection as a means to ensure that this goal remained possible. *See* W.M. BUSH, ANTARCTICA AND INTERNATIONAL LAW: A COLLECTION OF INTER-STATE AND NATIONAL DOCUMENTS 5–7 (1991) (discussing prior drafts of the Antarctic Treaty).

297. *See* Madrid Protocol, *supra* note 79, art. 2 (describing the treaty's objective as twofold: protecting the environment and devoting Antarctica to peace and science).

298. *Id.* art. 3.1.

299. *Id.* art. 3.2.

300. *Id.* art. 3.4(b). "Adverse impacts" and "impacts" are not further defined.

301. *See id.* art. 2 ("The Parties . . . hereby designate Antartica as a natural reserve, devoted to peace and science.").

change/climate engineering tension is clear when the protocol states that, "activities in the Antarctic Treaty area shall be planned and conducted so as to limit adverse impacts on the Antarctic environment and . . . to avoid: (i) adverse effects on climate or weather patterns; . . . [and] (iii) significant changes in the atmospheric, terrestrial (including aquatic), glacial or marine environments."[302] Both climate change and climate engineering will cause "significant changes" in the atmosphere and environment.[303] Moreover, the former, and perhaps the latter, will cause "adverse effects" on the earth's climate.[304] Climate engineering's effects, however, and certainly those from its research, are expected to be less severe.[305] Additionally, climate engineering is intended to avoid the adverse effects from climate change.[306] Other relevant commitments include environmental impact assessment, cooperation, monitoring, and reporting.[307] Notably, scientific activities are explicitly subject to impact assessment, and the only climate engineering assessment, to date, supported ocean fertilization research.[308]

Two particular provisions in the Annexes could present barriers to climate engineering research. First, if an activity "results in the significant adverse modification of habitat," it would require a permit from the state's "appropriate authority."[309] Second, ocean fertilization in Antarctic waters could be considered "discharge into the sea of . . . any other chemical or other substances, in quantities or concentrations that are harmful to the marine environment," and thus prohibited.[310] The wording in both cases,

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302. *Id.* art. 3.2(b).

303. *See supra* Parts I, II (outlining the consequences of climate change engineering).

304. *See supra* Part II (describing climate engineering methods).

305. *See supra* note 65 and accompanying text (comparing the relative impacts of climate change and engineering).

306. *See supra* Part II.

307. *See* Madrid Protocol, *supra* note 79, arts. 3.2, 6, 8, 17 (imposing on the Parties obligations to cooperate in the planning and conduct of activities in the Antarctic, to complete environmental evaluations, to monitor environmental indicators, and to circulate information to other Parties).

308. *See id.* art. 6 (requiring environmental impact assessments); Karen N. Scott, *Scientific Rhetoric and Antarctic Security*, *in* ANTARCTIC SECURITY IN THE TWENTY-FIRST CENTURY 284 (Alan D. Hemmings et al. eds., 2012) (citing the assessed and approved project by the New Zealand National Institute of Water and Atmospheric Research). Simultaneously, assessments of any activity "likely to have more than a minor or transitory impact" must consider its effects on the conduct of scientific research. *See* Madrid Protocol, *supra* note 79, Annex I, art. 3.2 (requiring this consideration).

309. *See* Madrid Protocol, *supra* note 79, Annex II, arts. 1, 3 (defining "harmful interference" to include significant adverse modification of habitats, and precluding "harmful interference" except when allowed by permit). A permit is also required for research activities in "Specially Protected or Managed Areas." *See id.* Annex V, art. 4 (establishing when a Party seeking to conduct scientific research is required to have a permit).

310. *Id.* Annex IV, art. 4.

however, requires that the environmental damage be certain and not merely speculative.[311] Field experiments, and particularly those of initially small scales, would be unlikely, or at least uncertain, to have such effects.[312] In addition, ships operated by governments on a noncommercial basis are exempt from the latter provision.[313]

J. Convention for the Protection of the Marine Environment of the North-East Atlantic

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) is a regional marine MEA that is important because of the governed regions' proximity to, and the participation of, countries that are leaders in climate engineering research, such as the United Kingdom and Germany.[314] The OSPAR Convention regulates activities that may impact the environment of the northeast Atlantic Ocean, including the North Sea and part of the Arctic Sea.[315] Under this convention, "pollution" is defined in much the same way as in the LC-LP, the LRTAP Convention, and UNCLOS.[316] Thus greenhouse gases and, arguably, global warming are included in the definition of pollution. As a consequence, the climate change/climate engineering tension is brought to the fore by the OSPAR Convention's most relevant provision, which requires Parties to "take all possible steps to prevent and eliminate pollution and shall take the necessary measures to protect the maritime area against the adverse effects of human activities so as to safeguard human health and to conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected."[317] The final reference to restoration

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311. *See id.* at (defining "harmful interference" to include only particular activities and only prohibiting the discharge of noxious substances as defined specifically in Annex II or that are harmful to marine environment).

312. *See generally* Parson & Keith, *supra* note 56, at 1279 (arguing that the environmental impact of field experiments would be limited).

313. *See* Madrid Protocol, *supra* note 79, Annex IV, art. 11 (stating that Annex IV of the Protocol does not apply to ships owned or operated by a State and operated only for non-commercial service).

314. *See generally* OSPAR Convention, *supra* note 75 (demonstrating that both countries are signatories of the Convention); Parker & Keith, *supra* note 128 (discussing the leaders of climate engineering research).

315. *See* OSPAR Convention, *supra* note 75, art. I (explaining that "maritime area" under the treaty generally includes the Atlantic and Arctic Ocean north of thirty-six degrees north latitude).

316. *See id.* (defining "pollution" to include introductions of substances or energy into the maritime area that results in hazards to health, harm to the environment, or other damage).

317. *Id.* art. 2.1(a).

endorses the general concept of human interventions in the natural environment in order to mitigate prior adverse effects.

A handful of other articles in the OSPAR Convention also shape its relation to climate engineering field research. First, scientific research (which remains undefined) is encouraged in order to "further the aims of the Convention," potentially lending some weight to climate engineering experiments.[318] Second, Parties are to apply both the precautionary principle and the polluter pays principle.[319] Although the former favors climate engineering research in the context of the UNFCCC, this would not be the case here, as it calls only for "preventive measures" in the face of uncertain risks.[320] Instead, this formulation of the precautionanry principle would argue for proceeding with great caution—if at all—if a proposed climate engineering field test were to pose a significant environmental risk.[321] In contrast, the polluter pays principle would support the research of climate engineering because the work is presently funded by those States that have contributed more to historical greenhouse gas emissions.[322] Third, in an article reminiscent of one in UNCLOS, Parties must carry out their obligations in a manner that does not transfer pollution to the sea outside of the covered area, or to another part of the environment.[323] This would rule out large-scale field research if early research indicated that further action would protect the OSPAR area while polluting other areas. Fourth, in the event of transboundary pollution, which could occur with climate engineering field tests, Parties commit to consult one another in order to try to reach an agreement, and either Party can seek the advice of the OSPAR Convention's governing Commission.[324] Finally, Parties that are responsible for climate engineering research would be subject to procedural

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318. *See id.* art. 8 (stating that the Parties must establish programs of scientific or technical research and report the results of that research).

319. *See id.* art. 2.2 (requiring the Parties to apply these principles in assessing state conduct).

320. *See id.* ("[P]reventive measures are to be taken when there are reasonable grounds for concern that substances or energy introduced, directly or indirectly, into the marine environment may bring about hazards to human health, harm living resources and marine ecosystems, . . . even when there is no conclusive evidence of a causal relationship . . . .").

321. *See* Reynolds & Fleurke, *supra* note 132, at 104–05 (introducing and defining the precautionary principle).

322. *See generally* Parker & Keith, *supra* note 128 (documenting public funding of climate engineering projects). Climate engineering research is presently led by Germany, the United Kingdom, the European Union, and the United States, all of which are near the top of historic greenhouse gas emissions. *Id.*

323. *See id.* art. 2.4 ("The Contracting Parties shall apply the measures they adopt in such a way as to prevent an increase in pollution of the sea outside the maritime area or in other parts of the environment.").

324. *See id.* art. 21 (agreeing to enter into a consultation with any concerned state and stating that any party may seek the advice of the Commission).

obligations including environmental monitoring, reporting, and providing public access to the relevant information.[325]

Ocean fertilization under the OSPAR Convention warrants some final attention. Dumping, which is defined similarly to the definition in UNCLOS and the LC-LP, is generally prohibited except in a handful of circumstances.[326] As witnessed under the LC-LP, whether ocean fertilization and its research are dumping under this definition is unclear.[327] Most OSPAR Convention Parties are also participants in the LC-LP (and in the London Protocol specifically) and would likely defer to the detailed rules of the latter.[328] Furthermore, the Commission has passed a "Code of Conduct for Responsible Marine Research," which, although not binding, dissuades scientists from changing populations or marine habitats.[329] Regardless, this is not especially relevant, as the North Atlantic is less suitable for ocean fertilization.[330]

K. Convention on Environmental Impact Assessment in a Transboundary Context

The Convention on Environmental Impact Assessment in a Transboundary Context (the Espoo Convention)[331] was developed through the UNECE in order to clarify and expand States' commitments to assess potential transboundary environmental impacts, to share those assessments with the public and other States, and to reduce significant environmental transboundary effects.[332] The Espoo Convention should improve

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325. *See id.* art. 6 (discussing environmental monitoring); *id.* art. 9 (discussing public access to information); *id.* art. 22 (discussing reporting requirements).

326. *See id.* arts. 1, 4, Annex II (defining and regulating dumping).

327. *See supra* Part IV.H (discussing the LC-LP).

328. *Compare OSPAR Convention—Contracting Parties*, OSPAR COMISSION, http://www.ospar.org/content/content.asp?menu=01481200000026_000000_000000 (last visited May 22, 2014) (listing the signatories to the Ospar Convention), *with* Office for the London Convention and Protocol, *supra* note 261 (listing the signatories to the London Convention and Protocol).

329. *See* OSPAR Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area, Annex 6, ¶¶ 12–13, 2008, OSPAR Doc, 08/24/1 (stating that responsible marine science includes a responsibility to avoid long-term changes or any damage to species or habitats).

330. *See* Williamson et al., *supra* note 33, at 477 (stating that the Southern Ocean is the area with the greatest potential for ocean fertilization because iron is the limiting nutrient there).

331. Convention on Environmental Impact Assessment in a Transboundary Context, Feb. 25, 1991, 1989 U.N.T.S. 309 [hereinafter Espoo Convention].

332. *See generally id.* (committing to "take all appropriate and effective measures to prevent, reduce and control significant adverse transboundary environmental impact"). Most industrialized nations, except for Russia and the United States, have joined the Espoo

transparency, public participation, and international cooperation in the lead-up to large-scale climate engineering field trials. Its definitions of "impact" and "transboundary impact," as well as its criteria for a significant proposed activity, are each clearly broad enough to include large-scale climate engineering field trials.[333] Greenhouse gas emissions and climate change are not be covered, however, as the agreement applies only to "proposed activities" that are "subject to a decision of a competent authority in accordance with an applicable national procedure."[334] Note that the Espoo Convention only applies to potential transboundary environmental impacts between two Parties to the Convention, and not to effects that are intrastate, occur in nonstate areas, or occur in a non-party state.[335]

The Espoo Convention requires Parties to "take all appropriate and effective measures to prevent, reduce and control significant adverse transboundary environmental impact from proposed activities."[336] Thus, the government of any Party that is considering approval of such a field trial that may impact another Party would be subject to a number of procedural obligations, most of which should be fulfilled before the activity is approved.[337] Chief among these is the duty to notify potentially affected Parties and, if those countries agree, to undertake an environmental impact assessment in such a manner as to permit participation by the public living in the area likely to be affected, including the public of the other affected countries.[338] The origin Party and the concerned party are then required to consult each other on the proposed project.[339] When making the final decision to approve the proposed activities, the origin Party is to take into account the impact assessment, public comments, and the consultation with the concerned Party.[340] The Espoo Convention also calls for post-project

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Convention. *See Convention on Environmental Impact Assessment in a Transboundary Context Status*, UNITED NATIONS TREATY COLLECTION (May 4, 2014 7:04 PM), https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_ no=XXVII-4&chapter=27&lang=en (providing a list of the signatories to the Espoo Convention) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

333. *See id.* art. 1 (defining "impact" and "transboundary"); *see id.* app. III (providing criteria for activities not listed in Appendix 1 that potentially qualify as significant for purposes of the agreement).

334. *Id.* art. 1(v).

335. *See id.* art. 1(viii) (noting that, under the Convention, "transboundary impact" is limited to impact within the jurisdiction of a signatory).

336. *Id.* art. 2.1.

337. *See id.* art. 3 (explaining a Party's obligation to notify other Parties of potential environmental impacts).

338. *See id.* art. 2 (detailing the procedures necessary for an impact assessment).

339. *See id.* art. 5 (imposing requirements on consultation and impact assessment).

340. *See id.* art. 6(1) ("The Parties shall ensure that, in the final decision . . . due account is taken of the outcome of the environmental impact assessment, including

analysis, and if there are "reasonable grounds for concluding that there is a significant adverse transboundary impact . . . concerned Parties shall then consult on necessary measures to reduce or eliminate the impact."[341]

L. Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters

Like the Espoo Convention, the Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (the Aarhus Convention)[342] is an MEA developed within the UNECE in order to improve the disclosure of information and access to decision-making for actions that may have an environmental impact.[343] It would commit Parties to carry out several procedural duties in the event of large-scale climate engineering field tests.[344] In general, "each Party shall guarantee the rights of access to information, public participation in decision-making, and access to justice in environmental matters."[345] Notably, these matters need not be transboundary, and the Espoo Convention consequently establishes these rights for individuals and NGOs with respect to their own governments.[346] Furthermore, these rights apply even in the absence of present or potential harm.[347] The Convention details standards for the collection and provision of relevant information, which is broadly defined.[348] Although the original Aarhus Convention

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the . . . documentation, as well as the comments thereon received . . . and the outcome of the consultations . . . .").

341. *Id.* art. 7.

342. Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, June 25, 1998, 2161 U.N.T.S. 447 [hereinafter Aarhus Convention].

343. *See generally id.* (recognizing that public access to information is important for environmental protection). The UNECE countries that are not a party to the Aarhus convention include the United States, Canada, and Russia. *See Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters* ***Status***, UNITED NATIONS TREATY COLLECTION (May 4, 2014 6:57 PM), https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no= XXVII-13&chapter=27&lang=en (providing a list of the signatories to the Aarhus Convention) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

344. *See generally* Aarhus Convention *supra* note 342 (establishing requirements on signatories prior to taking actions that may affect the environment).

345. *Id.* art. 1.

346. *See id.* pmbl. ("Recognizing further the importance of the respective roles that individual citizens, non-governmental organizations and the private sector can play in environmental protection.").

347. *See id.* arts. 3–5 (listing the obligations of parties under the Aarhus Convention).

348. *See id.* art. 2.3 (defining "environmental information" to include "activities or measures, including administrative measures, environmental agreements, policies, legislation, plans and programmes, affecting or likely to affect the elements of the

obligates Parties to merely "encourage [private] operators whose activities have a significant impact on the environment to inform the public regularly of the environmental impact of their activities and products,"[349] its Kiev Protocol on Pollutant Release and Transfer Registers expands this into an obligation for private actors to collect and publish relevant data.[350] The right for participation is somewhat similar to the process of environmental impact assessment in the Espoo Convention,[351] and is limited to those members of the broad "public concerned."[352] The provision in the Aarhus Convention for access to justice establishes minimum standards of redress for members of the public with sufficient interests in any environmental laws that have been violated.[353]

V. Nonbinding Multilateral Environmental Agreements

This section analyzes four nonbinding international agreements that may shape how climate engineering research will be regulated. Although nonbinding, they constitute a key component of international soft law and provide a sense of where the international community stands.

A. Provisions for Co-operation Between States in Weather Modification

In 1980, partially in response to the passage of ENMOD, the leadership of the UN Environmental Programme (UNEP) drafted and

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environment . . . , and cost-benefit and other economic analyses and assumptions used in environmental decision-making"); *id.* arts. 4–5 (explaining the procedure for collecting environmental information and detailing the required access to, and dissemination of, such information).

349. *Id.* art. 5.6.

350. *See* Protocol on Pollutant Release and Transfer Registers to the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, May 21, 2003, 005/2010 U.K.T.S. Cm. 7879 (mandating that each operator impacting the environment regularly inform the public of the environmental impact and any voluntary auditing schemes).

351. *Compare* Aarhus Convention, *supra* note 342, art. 6.7 ("Procedures for public participation shall allow the public to submit, in writing or, as appropriate, at a public hearing or inquiry with the applicant, any comments, information, analyses or opinions that it considers relevant to the proposed activity."), *with* Espoo Convention, *supra* note 331, art. 2.2 (providing for public participation).

352. *See* Aarhus Convention, *supra* note 342, art. 2.5v ("'The public concerned' means the public affected or likely to be affected by, or having an interest in, the environmental decision-making; for the purposes of this definition, non-governmental organizations promoting environmental protection and meeting any requirements under national law shall be deemed to have an interest.").

353. *See id.* art. 9 (establishing that a Party seeking redress must either have a "sufficient interest" or maintain that a right has been impaired).

approved Provisions for Co-operation between States in Weather Modification.[354] Although weather and climate are scientifically distinct, the Provisions define "weather modification" to include climate interventions, and this is thus a particularly important nonbinding legal document.[355] In general, the document provides qualified support for weather modification while calling for procedural duties to be imposed on the States under whose authority these activities may take place. For example, it notes "the possible benefits which weather modification may hold for mankind and the environment"[356] and asserts that "[w]eather modification should be dedicated to the benefit of mankind and the environment."[357] The Provisions further call for "[e]xchange of information, notification, consultation and other forms of co-operation."[358] For potential transboundary impacts from weather modification, this provision recommends environmental impact assessments and efforts "to ensure that [weather modification activities] do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."[359]

B. Declaration of the United Nations Conference on the Human Environment

Modern international environmental law can be traced to the 1972 United Nations Conference on the Human Environment and its Declaration (the Stockholm Declaration).[360] To the extent that it still conveys the priorities of contemporary international environmental law, it lends support to climate engineering field research, provided that such activity is done in a manner that minimizes transboundary harm.[361] The Stockholm Declaration is a thoroughly anthropocentric document, emphasizing

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354. *See generally* Provisions for Co-operation between States in Weather Modification, U.N.E.P. Dec. 8/7/A, U.N. Doc. UNEP/GC/8/7/A (Apr. 29, 1980) (setting out States' obligations to each other with respect to weather modification).

355. *See id.* pt. 1(b) ("[A]ny action performed with the intention of producing artificial changes in the properties of the atmosphere for purposes such as increasing, decreasing or redistributing precipitation or cloud coverage, moderating severe storms and tropical cyclones, decreasing or suppressing hail or lightning or dissipating fog.").

356. *Id.* cl. 5.

357. *Id.* pt. 1(a).

358. *See id.* pt. 1(b) (explaining that these further provisions should be carried out in good faith and without delay).

359. *Id.* pt. 1(f).

360. Declaration of the United Nations Conference on the Human Environment, *adopted* June 16, 1972, 11 I.L.M. 1416 [hereinafter Stockholm Declaration].

361. *See id.* ¶¶ 6–7 (stating that "through fuller knowledge and wiser action, we can achieve for ourselves and our posterity . . . an environment more in keeping with human needs" but that to "achieve this environmental goal will demand the acceptance of responsibility . . . at every level, all sharing equitably in common efforts").

humans' responsibility to "manage" the "human environment" in order to "protect and improve" it.[362] For example, it proclaims that "man [sic] must use knowledge to build, in collaboration with nature, a better environment."[363] Additionally, its first principle is that "he [sic] bears a solemn responsibility to protect and improve the environment for present and future generations."[364] The focus on "human environment" further implies a prioritization of the environment as it relates to the well being of people, and that preservation of the natural environment for its own sake is secondary.[365] Furthermore, the Stockholm Declaration calls for science and technology to be "applied to the identification, avoidance and control of environmental risks and the solution of environmental problems and for the common good of mankind"[366] and for "the free flow of up-to-date scientific information and transfer of experience."[367] It also explicates principles for the minimization and reduction of transboundary harm,[368] for the development of liability for transboundary harm,[369] and for international cooperation in protecting and improving the environment.[370]

C. Rio Declaration on Environment and Development

Twenty years later, representatives of most countries agreed upon the Rio Declaration on Environment and Development (Rio Declaration).[371] Although it retains a somewhat anthropocentric focus, almost entirely absent are the calls to manage and improve the Earth.[372] Instead, it focuses

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362. *See generally id.* (outlining the "special responsibility to safeguard and wisely manage the heritage of wildlife and its habitat").

363. *Id.* ¶ 6.

364. *Id.* princ. 1.

365. *See* Dinah Shelton, *Human Rights, Environmental Rights, and the Right to Environment*, 28 STAN. J. INT'L L. 103, 108 (1991) ("The 1972 Stockholm Declaration on the Human Environment suggests that human benefit is the primary reason for respecting the environment . . . .").

366. Stockholm Declaration, *supra* note 360, princ. 18.

367. *Id.* princ. 20.

368. *See id.* princ. 21 ("States have . . . the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.").

369. *See id.* princ. 22 ("States shall cooperate to develop further the international law regarding liability and compensation for the victims of pollution and other environmental damage caused by activities within the jurisdiction or control of such States to areas beyond their jurisdiction.").

370. *See id.* princ. 24 (stating that international efforts to protect and improve the environment "should be handled in a cooperative spirit by all countries").

371. Rio Declaration on Environment and Development, *adopted* June 14, 1992, 31 I.L.M. 874 [hereinafter Rio Declaration].

372. *See id.* at princ. 1 ("Human beings are at the centre of concerns for sustainable development . . . .").

on the interrelation between environmental protection and the needs of the world's poor.[373] Some of the principles of the Rio Declaration, however, could be interpreted as favoring climate engineering research. For example, it calls for "improving scientific understanding" and for developing "new and innovative technologies."[374] Furthermore, because the research would largely be financed by industrialized countries, the Rio Declaration's discussion of "common but differentiated responsibilities" and of the "internalization of environmental costs" appear supportive of climate engineering research.[375] The Rio Declaration also invokes precaution: "[w]here there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."[376] Given that the threats of climate change appear to be more serious and irreversible than those of climate engineering,[377] and that the latter is expected to have low financial costs,[378] the Rio Declaration—like the UNFCCC—appears to argue for climate engineering research.[379] On the other hand, another principle states that countries should "discourage or prevent the relocation and transfer to other States of any activities and substances that cause severe environmental degradation or are found to be harmful to human health."[380] If field trials were to somehow put one human population at particular risk, this Principle may be violated.[381] Finally, some of the principles call for procedural obligations on the part of countries that may approve climate engineering field trials.[382] Perhaps most importantly, such

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373. *See id.* princ. 6 (stating that those countries "least developed and those most environmentally vulnerable" are to be "given special priority").

374. *See id.* princ. 9 ("States should cooperate to . . . improv[e] scientific understanding through exchanges of scientific and technological knowledge, and . . . enhance[e] the development, adaptation, diffusion and transfer of technologies, including new and innovative technologies.").

375. *See id.* princ. 7 ("States have common but differentiated responsibilities."); *id.* at princ. 16 ("National authorities should endeavour to promote the internalization of environmental costs.").

376. *Id*. princ. 15.

377. *See supra* note 65 (comparing the effects of climate change with the more limited effects of climate engineering).

378. *See supra* note 121 and accompanying text (discussing the relative low cost of climate engineering).

379. *See supra* notes 130–132 and accompanying text (discussing the UNFCCC's support for cost-effective climate engineering research).

380. Rio Declaration, *supra* note 371, at princ. 14.

381. *See id.* princ. 14 ("States should effectively cooperate to discourage or prevent the relocation and transfer to other States of any activities and substances that cause severe environmental degradation or are found to be harmful to human health.").

382. *See id.* princ. 17 (requiring States to prepare environmental impact assessments); *id.* princ. 19 ("States shall provide prior and timely notification and relevant information to potentially affected states . . . .").

steps "should, as far as possible, be based on an international consensus."[383] The governments of these countries should also conduct environmental impact assessments,[384] notify affected States,[385] and provide public access to relevant information.[386]

D. UN General Assembly

Finally, the UN General Assembly approved a 2007 resolution that, among other things, "encourages States to support the further study and enhance understanding of ocean iron fertilization."[387]

VI. Customary International Law

Customary international law concerning transboundary harm will also apply to climate engineering field research. The customary law examined here has been discussed above, where it is embodied in various MEAs.

A. Prevention

The customary international law of preventing potential transboundary environmental impacts is among the oldest and most-established components of international environmental law. [388] States' commitments in this regard are to "prevent, reduce, and control transboundary pollution and environmental harm resulting from activities within their jurisdiction or control . . . [and] to cooperate in mitigating transboundary environmental risks and emergencies, th[r]ough notification, consultation, negotiation, and in appropriate cases, environmental impact assessment."[389] Such customary law has developed through court cases and

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383. *Id.* princ. 12.

384. *See id.* princ. 17 (calling on States to make environmental impact assessments when their activities "are likely to have a significant adverse impact on the environment . . . .").

385. *See id.* princ. 19 (listing the instances that States need to notify one another of potential environmental impacts).

386. *See id.* princ. 10 ("States shall facilitate and encourage public awareness and participation by making information widely available.").

387. G.A. Res. 62/215, ¶ 98, U.N. Doc. A/RES/62/215 (Dec. 22, 2007).

388. *See* DANIEL BODANSKY, THE ART AND CRAFT OF INTERNATIONAL ENVIRONMENTAL LAW 198 (2010) (noting that the "duty to prevent transboundary pollution" is seen as the "most firmly established customary norm" of international environmental law).

389. BIRNIE ET AL., *supra* note 68, at 137.

state practice.[390] Using the International Law Commission (ILC) Draft Articles on Prevention of Transboundary Harm from Hazardous Activities[391] as a guide, some forms of large-scale climate engineering field research could pose a "significant risk of causing significant transboundary harm."[392] Although not defined in the articles, the accompanying commentary clarifies this phrase as being objectively and reasonably foreseeable, with the potential harm as being "more than detectable but need not be at the level of 'serious' or 'substantial.' The harm must lead to a real detrimental effect on matters such as, for example, human health, industry, property, environment or agriculture in other states."[393] If climate engineering field research were to be undertaken, then the origin State's duties would include implementing "all appropriate measures to prevent" the harm,[394] requiring authorization for a domestic party to conduct the activity in question,[395] performing an environmental impact assessment,[396] notifying States likely to be affected,[397] informing the public likely to be affected,[398] and developing contingency plans to prepare for an emergency.[399] The precise steps to prevent and minimize the harm are subject to consultations between the countries,[400] and are to be "based on an equitable balance of interests,"[401] whose relevant factors for consideration include:

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390. *See id.* at 138 (explaining that the duty to prevent potential transboundary harm is evidenced by treaties, state action, and case law).

391. 53 U.N. GAOR Supp. No. 10, art. 2(a), UN Doc. A/56/10 (2001), *reprinted in* [2001] 2 Y.B. Int'l L. Comm'n 146 U.N. Doc. A/CN.4/SER.A/2001/Add.1 (Part 2) [hereinafter *Draft Articles on Prevention of Transboundary Harm*].

392. *See id.* art. 1 ("Any activity which involves the risk of causing significant transboundary harm through the physical consequences is within the scope of the articles."); *id.* art. 1 cmt. 14 ("The mere fact that harm eventually results from an activity does not mean that the activity involved a risk, if no properly informed observer was or could have been aware of that risk at the time the activity was carried out.").

393. *Id.* art. 2 cmt. 4.

394. *See id.* art. 3 ("The State of origin shall take all appropriate measures to prevent significant transboundary harm or at any event to minimize the risk thereof.").

395. *See id.* art. 6 (listing the circumstances under which a State may require prior authorization before a party can act).

396. *See id.* art. 7 (requiring States to consider any environmental impact assessment when authorizing certain activities).

397. *See id.* art. 8 (requiring States to notify other States likely to be affected if the assessment required in art. 7 "indicates a risk of causing significant transboundary harm").

398. *See id.* art. 13 (requiring States to inform the public likely to be affected).

399. *See id.* art. 16 ("The State of origin shall develop contingency plans for responding to emergencies.").

400. *See id.* art. 9 ¶ 1 (stating that "[t]he states concerned shall enter into consultations").

401. *Id.* art. 9 ¶ 2.

> the importance of the activity, taking into account its overall advantages of a social, economic and technical character for the State of origin in relation to the potential harm for the State likely to be affected; . . . [and] the economic viability of the activity in relation to the costs of prevention and to the possibility of carrying out the activity elsewhere or by other means or replacing it with an alternative activity . . . .[402]

These two phrases again pose the climate change/climate engineering tension. The "equitable balance of interests" creates a significant burden for the potentially affected country to argue for strong preventative measures, particularly if the state of origin were to face high climate change damages and high costs to mitigate these damages.[403] An alternate interpretation of these factors, however, could be that climate engineering field research does not present concentrated economic benefits to the country performing it.[404] Instead, its benefits would be diffused throughout the world, whereas the risks may be limited to a small number of countries.[405] Ultimately, how a court may rule would depend on the particular context[406] and the extent to which the state of risk origin had acted with due diligence.[407]

The second half of the customary law of prevention is for countries to cooperate to mitigate risks.[408] Specific duties herein include notification, consultation, and negotiation.[409] For example, according to the Rio Declaration, the notification should be "prior and timely" and consist of "relevant information."[410] Consultations should occur "at an early stage and

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402. *Id*. art. 10(b), (e).

403. *See supra* note 121 and accompanying text (discussing the costs of SRM climate engineering research).

404. *See id.* at 103 (discussing the potential benefits of SRM climate engineering research).

405. *See id.* at 103–04 (arguing that deploying SRM has a "reasonable chance" of "significantly reduc[ing] the net damage from climate change to humans and the environment," and its smaller costs would be considered insurance).

406. *See Draft Articles on Prevention of Transboundary Harm*, *supra* note 392, art. 10 (stating factors to consider in the "equitable balance of interests" required in article 9).

407. *See id.* art. 3 cmts. 7–8 (defining due diligence and explaining its prevalence in the "protection of the environment from harm").

408. *See* BIRNIE ET AL., *supra* note 68, at 137 (listing theStates that have a duty to "cooperate in mitigating transboundary environmental risks and emergencies").

409. *See id.* (requiring States to mitigate risks through "notification, consultation, negotiation, and in appropriate cases, environmental impact assessment").

410. *See* Rio Declaration, *supra* note 371, princ. 19 (describing requirements of notice and consultation).

in good faith."[411] Most States under whose jurisdiction or control climate engineering field trials would occur would require an environmental impact assessment under domestic law, even in the absence of transboundary risks.[412] If they were to occur in areas beyond national jurisdiction, then MEAs including UNCLOS and the Antarctica Treaty system would apply.[413] If the proposal raised the prospect of transboundary impacts, then the Espoo Convention, customary international law, and many national laws would call for assessments.[414] Regardless, the details of impact assessments are often more contentious than whether an assessment is required.[415] In a domain as novel as climate engineering field experimentation, uncertainty may prevail, and both a judicious interpretation of the precautionary principle as well as political wisdom calls for erring on the side of a more thorough assessment.[416] There are, however, limited exceptions, as not every country has an assessment law or is a party to the Espoo Convention.[417] Furthermore, customary law, which requires assessment, does not apply to effects completely within national boundaries or to global impacts.[418]

B. Responsibility and Liability

The international law on ex post responsibility and liability for transboundary damage remains less developed than the law regarding its

411. *See id.* (discussing the obligations between nations when conducting experiments that affect the environment).

412. *See* BIRNIE ET AL., *supra* note 68, at 165 ("An [environmental impact assessment] is fundamental to any regulatory system which seeks to identify environmental risk, integrate environmental concerns into development projects and promote sustainable development.").

413. *See* SANDS & PEEL, *supra* note 74, at 605–08 (discussing when an environmental assessment is required under a variety of international treaties covering the environment).

414. *See id.* at 605, 611 (discussing the use of environmental impact assessments in the context of customary law and the Espoo Convention).

415. *See id.* at 602 (noting that while it is generally understood when environmental impact assessments need to be made, there is much less consensus as to what should be included in the assessments).

416. *See* BETZ AT AL., *supra* note 240, at 99 (suggesting that environmental impact assessments should be more thorough for climate engineering because there is a greater risk of hazard with climate engineering) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

417. *See* SANDS & PEEL, *supra* note 74, at 601 (noting that environmental impact assessments "have been progressively adopted in a very large number of legal systems," suggesting that not all legal systems require assessments); *id.* at 610 (noting that the Espoo Convention only commits Parties who signed the Convention).

418. *See* BIRNIE ET AL., *supra* note 68, at 167 ("[A]t present general international law neither requires states to assess possible global effects for effects wholly within their own borders.").

prevention.[419] For example, the only MEAs examined here that establish liability are the Space Liability Convention[420] and UNCLOS.[421] Under customary international law, if the state that is the source of damage violated international law, including noncompliance with the customary international law of preventing transboundary harm, it should cease the activity, assure that the act will not recur, and make reparations for the injuries.[422] In the absence of a violation, climate engineering field studies—certainly at larger scales—likely qualify as ultra-hazardous activities,[423] for which there is often absolute or strict liability.[424] Although, such absolute or strict liability could, in theory, be considered a part of customary international law due to its presence in national and international laws and for a handful of specific activities, there is not yet adequate state practice for this to be the case.[425] The draft ILC principles for Transboundary

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419. *See id.* at 303 (acknowledging an "absence of clarity concerning remedies available to states and their scope").

420. *See* Space Liability Convention, *supra* note 217 and accompanying text.

421. *See* UNCLOS *supra* note 247 and accompanying text. An Annex to the Madrid Protocol for liability in the Antarctic is not yet in force. *See The Protocol on Environmental Protection to the Antarctic Treaty*, SECRETARIAT OF THE ANTARCTIC TREATY, http://www.ats.aq/e/ep.htm (last visited Jan. 28, 2014) ("Annex VI on *Liability Arising from Environmental Emergencies* was adopted by the 28th ATCM in Stockholm in 2005 and will enter into force once approved by all Consultative Parties.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

422. *See* Factory at Chorzów (Ger. v. Pol.), 1928 P.C.I.J. (ser. A) No. 17, at 47 (Sept. 13, 1928), *available at* http://www.icj-cij.org /pcij/serie_A/A_17/54_Usine_de_Chorzow_Fond_Arret.pdf (highlighting that reparations should attempt to "wipe out all of the consequences of the illegal act"); *Draft Articles on Responsibility of States for Internationally Wrongful Acts*, 53 U.N. GAOR Supp. No. 10, art. 1–2, 30–31, 34–39, U.N. Doc. A/56/10 (2001), *reprinted in* [2001] 2 Y.B. Int'l L. Comm'n 26 U.N. Doc. A/CN.4/SER.A/2001/Add.1 (Part 2) (explaining a State's liability when it violates international law); *see also id.* art. 24–25 (providing the possibility that a state that is seriously threatened by climate change may defend a violation of international law based upon necessity or even distress).

423. *See Draft Articles on Prevention of Transboundary Harm*, *supra* note 392, art. 1, cmt. ¶ 2 ("An ultra-hazardous activity is perceived to be an activity with a danger that is rarely expected to materialize but might assume, on that rare occasion, grave (more than significant, serious or substantial) proportions.").

424. *See* SANDS & PEEL, *supra* note 74, at 712 ("Strict liability for ultrahazardous activities might be considered a general principle of law . . . .").

425. *See id.* (explaining that while "[s]trict liability for ultrahazardous activities might be considered a general principle of law . . . ." and some treaties include strict liability, the current overall landscape of international law does not support strict liability as customary law). Nuclear energy, space activities, maritime transportation of oil, and the transportation and disposal of hazardous waste share strict or absolute, limited liability. *See* C. WILFRED JENKS, LIABILITY FOR ULTRA-HAZARDOUS ACTIVITIES IN INTERNATIONAL LAW 160–67 (1967) (discussing when liability may exist for climate modification).

Damage due to Hazardous Activities,[426] however, call for States to "ensure that prompt and adequate compensation is available for victims" and to impose strict liability on the operators of the activity.[427] In the case of climate engineering and its research, demonstrating causation would be particularly daunting.[428]

VII. Conclusions and Lingering Issues

Existing international environmental law provides both a regulatory and normative framework that will influence climate engineering field research and its regulation, and is, on the whole, favorable toward this research. Throughout these considerations, the climate change/climate engineering tension looms, and how a particular proposed climate engineering field experiment would fare under international environmental law is to a great degree contingent upon the assessments of the risks of climate change, and of both the risks and potential benefits of the field test in question. It is important to emphasize that this favorable setting does not necessarily extend to the deployment of large-scale climate engineering projects. Of course, almost none of this law was developed with climate engineering in mind and it consequently forms an inconsistent, sometimes contradictory legal environment. Furthermore, drawing general conclusions is difficult, as the actual rights and obligations of States will depend on numerous factors such as the form of climate engineering being researched, its scale, its location, and the likelihood, magnitude, and location of potential transboundary effects. Nevertheless, a handful of specific conclusions exist.

There are five reasons for the generally positive international legal environment of climate engineering research. First, to the extent that the

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426. *Draft Principles on the Allocation of Loss in the Case of Transboundary Harm Arising out of Hazardous Activities*, 58 U.N. GAOR, Supp. No. 10, at princ. 4, U.N. Doc. A/61/10 (2006), *available at* legal.un.org/ilc/texts/instruments/english/draft articles/9_10_2006.pdf.

427. *See generally id.* (establishing strict liability for operators who partake in hazardous activities that cause transboundary harm).

428. *See* Toby Svoboda & Peter J. Irvine, *Ethical and Technical Challenges in Compensating for Harm Due to Solar Radiation Management Geoengineering*, 17 ETHICS, POL'Y & ENV'T (forthcoming 2014) (manuscript at 11) ("The uncertainty involved in attributing particular changes in climate to specific causes could make it very difficult to determine whether some harmful impact, such as a prolonged drought, is due to a deployed SRM technique or not."); *but see* Joshua B. Horton et al., *Liability for Solar Geoengineering: Historical Precedents, Contemporary Innovations, and Governance Possibilities*, 22 N.Y.U. ENVTL. L.J. (forthcoming 2015) (manuscript at 26) (arguing that "the problem of attribution does not necessarily appear to present an insurmountable barrier to crafting a workable regime").

MEAs reviewed here seek to protect the environment, they favor, at the least, research into climate engineering as a potential means to reduce risks to humans and the environment from climate change. International environmental law has a generally anthropocentric orientation, and that is evident throughout these MEAs. While climate engineering field research may present some threat to the natural environment, climate change is forecast to pose substantially more significant risks.[429] Furthermore, in several cases, greenhouse gases and/or climate change appear to satisfy the criteria for the pollution, damage, or adverse effects which the MEAs seek to reduce.[430] Therefore, to the extent that a balancing is suggested by these MEAs' commitments from States to reduce such pollution or damage and to protect the environment more generally, they channel and tilt favorably toward climate engineering research as a means to develop a potential additional response to climate change—even if it presents risks of its own.[431] At the same time, if a line of climate engineering research were to hold little potential to reduce climate change risks while presenting large risks of its own, then this balance would shift against the research.

Second, many of the agreements explicitly or implicitly encourage scientific research and technological development.[432]

Third, the development of climate engineering is also consistent with some principles of international environmental law, including common but differentiated responsibility, polluter pays, and—in some of its forms—the precautionary principle, which are invoked at various times by the agreements.[433]

Fourth, in several cases, climate engineering research is supported due to its projected high speed and low financial cost.[434]

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429. *See supra* note 65 and accompanying text.

430. *See supra* notes 71–75 and accompanying text.

431. *See supra* notes 60–62 and accompanying text.

432. *See* Kyoto Protocol, *supra* note 118 and accompanying text; UNFCCC, *supra* notes 125–26 and accompanying text; Vienna Convention, *supra* notes 170, 176 and accompanying text; ENMOD, *supra* notes 146–47 and accompanying text; LRTAP Convention, *supra* note 183 and accompanying text; Oslo Protocol, *supra* note 198 and accompanying text; Outer Space Treaty, *supra* note 210 and accompanying text; UNCLOS, *supra* notes 241–44 and accompanying text; Antarctica Treaty, *supra* notes 293, 297–99 and accompanying text; OSPAR Convention, *supra* note 318 and accompanying text; Stockholm Declaration, *supra* note 367 and accompanying text; Rio Declaration, *supra* note 374 and accompanying text.

433. *See* UNFCCC, *supra* notes 127–32 and accompanying text; Oslo Protocol, *supra* note 187 and accompanying text; OSPAR Convention, *supra* note 319 and accompanying text; Rio Declaration, *supra* notes 375–76 and accompanying text; *see also* Reynolds & Fleurke, *supra* note 132 and accompanying text.

434. *See* UNFCCC, *supra* notes 121–24 and accompanying text; LRTAP Convention, *supra* notes 185–87 and accompanying text.

Fifth and finally, all three agreements whose subject matter are most relevant to climate engineering favor climate engineering field research.[435] The UNFCCC calls for the avoidance of dangerous climate change for humanity's sake,[436] for the use of methods that are rapid and inexpensive,[437] for industrialized countries to shoulder the financial burden,[438] for precautionary action to mitigate the negative effects of climate change,[439] for the promotion of applicable scientific and technological research,[440] and for States to enhance reservoirs and sinks of greenhouse gases.[441] ENMOD and the UNEP Provisions for Weather Modification each encourage the development of peaceful climate engineering, in part to improve the environment for the sake of the human population.[442]

Despite being supportive of climate engineering research in general, existing law imposes duties on the part of the States that would be responsible for field research. For the most part, these are the procedural duties regarding the prevention and mitigation of transboundary harm, such as notification, assessment, consultation, and negotiation.[443] These are part of customary international law, and the MEAs provide further explicit detail for some situations, including that of risks to the environment in areas outside of state territory. The Espoo Convention adds public participation in the assessment and post-project analysis,[444] and the Aarhus Convention requires access to information and public participation in decision-making, even for projects that would have wholly domestic effects.[445]

Moreover, some of the binding MEAs impose particular constraints and prohibitions on parties to these agreements. Among these, the most general and most challenging to interpret is the statement of the CBD COP.

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435. *See supra* Part IV.A, IV.B, IV.C.
436. *See supra* notes 111–13 and accompanying text.
437. *See supra* notes 121–24 and accompanying text.
438. *See supra* notes 127–29 and accompanying text.
439. *See supra* notes 130–32 and accompanying text.
440. *See supra* notes 125–26 and accompanying text; *see also* Kyoto Protocol, *supra* note 118 and accompanying text.
441. *See supra* notes 115–18 and accompanying text.
442. *See* ENMOD, *supra* notes 143–47, and accompanying text; UNEP Provisions for Weather Modification, *supra* notes 356–58 and accompanying text.
443. *See* UNFCCC *supra* note 133 and accompanying text; CBD, *supra* note, 159 and accompanying text; LRTAP Convention, *supra* note 205 and accompanying text; Outer Space Treaty, *supra* note 214 and accompanying text; Madrid Protocol, *supra* notes 307–08 and accompanying text; OSPAR Convention, *supra* notes 324–25 and accompanying text; Stockholm Declaration, *supra* note 370 and accompanying text; Rio Declaration, *supra* note 384–86 and accompanying text; Weather Modification Provisions, *supra* notes 358–59 and accompanying text.
444. *See supra* note 332–41 and accompanying text.
445. *See supra* notes 343–53 and accompanying text.

While nonbinding, this statement indicates that the international community desires a greater degree of regulation, consideration of risks, and scientific justification before large-scale field research is undertaken.[446] In contrast, the the LC-LP framework for ocean fertilization and the more general London Protocal framework for marine geoengineering provide the clearest regulation, prohibiting it unless a project is deemed to be legitimate scientific research.[447] Another strong restriction on climate engineering research is the apparent prohibition on sulfur-based SAI SRM field tests within the territory of the Parties to the Gothenburg Protocol to the LRTAP Convention.[448] Throughout the world, climate engineering investigations must be non-hostile if they have "widespread, long-lasting or severe effects" and if conducted at sea and in Antarctica, they must be for peaceful purposes.[449] At sea, research must not undermine the protection of marine environment, cannot unjustifiably interfere with other legitimate uses of the sea, must use appropriate scientific methods and means, and is subject to the authority of coastal States in their territory, exclusive economic zones, and continental shelves. Furthermore, marine climate engineering work cannot merely transfer or transform pollution, although these provisions may apply only to climate engineering deployment. In the northeast Atlantic Ocean, if there are reasonable grounds that climate engineering research may present a hazard to human health or the environment, then the state is obligated to take "preventative measures."[450] In the Antarctic Treaty area, a permit may be needed in certain locations, and research projects must be cancelled if they threaten to harm the environment.[451] States would be liable for damage caused by climate engineering research in space or if they violate international law (although demonstrating causation will be difficult).[452] In theory, the sulfur-based SAI SRM field tests could be prohibited under the Montreal Protocol, if they were found to be significantly destructive to the ozone layer and if the Parties actually take novel action.[453]

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446. *See supra* notes 159–62 and accompanying text.

447. *See supra* notes 263–89 and accompanying text.

448. *See supra* notes 190–93 and accompanying text; *see also* Oslo Protocol, *supra* note 206 (noting that *large-scale* sulfur SAI SRM tests are not permitted under the Gothenburg and Oslo Protocol).

449. *See* ENMOD, *supra* notes 144–45 and accompanying text; UNCLOS, *supra* note, 245 and accompanying text; Madrid Protocol, *supra* note 301 and accompanying text; *see also* Outer Space Treaty, *supra* note 208, art. III (noting that, in space, activities must merely be "in the interest of maintaining international peace and security").

450. *See supra* notes 319–20 and accompanying text.

451. *See supra* notes 300, 309 and accompanying text.

452. *See* Outer Space Treaty and Space Liability Convention, *supra* notes 217–21 and accompanying text; UNCLOS, *supra* note 247; customary international law *supra* Part VI.B.

453. *See supra* notes 163–72 and accompanying text.

Finally, any law governing climate engineering research, whether it relies upon existing MEAs or otherwise, will be complicated by a determination of what qualifies as climate engineering research. Thus far, definitions have been employed that typically rely on the intention of the researcher or the effects of the research.[454] Intentions, however, are easily denied, and the precise effects of field research may remain partially unknown until after they are carried out.[455] Other important questions arise. In terms of scale, at what point does a small-scale project warrant the attention of domestic or international law, and at what point does a large-scale project become deployment?[456] How is research that investigates basic environmental processes or climate change (or at least claims to do so), yet could also be used to develop climate engineering potentially affected? But, determining how to define "climate engineering research" and its thresholds will likely be the most challenging aspect in the development of its regulation.

Despite these duties and limited restrictions, extant international environmental law remains on the whole favorable to responsibly conducted climate engineering field research, particularly due to its potential to reduce harm to humans and the environment. Although international law does influence state behavior, state interests and global and domestic politics arguably play larger roles in shaping the actions of decision makers.[457] How a potentially controversial, risky, large scale climate engineering field test is perceived by the international community depends not only on existing international environmental law but also on international and domestic political circumstances, the severity of current and forecast climate change, the reputations and nationalities of the

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454. *See supra* notes 143, 159, 264, 279, 355 and accompanying text. It is important to note that the definition of "marine geoengineering" used in the amendment to the London Protocol requires only a "deliberate intervention in the marine environment to manipulate natural processes."

455. *See* Kelsi BRACMORT & RICHARD K. LATTANZIO, CONG. RESEARCH SERV., R41371, GEOENGINEERING: GOVERNANCE AND TECHNOLOGY POLICY 1 (2013) (discussing how some observers "respond that the uncertainties of geoengineering may only be resolved through further scientific and technical examination").

456. *See* Parson & Keith, *supra* note 56, at 1278 (suggesting thresholds for defining categories of climate engineering research).

457. *See generally* Steinberg, *supra* note 105 (surveying the neorealist approach to international law and international relations); Barbara Koremenos, *Institutionalism and International Law*, *in* INTERDISCIPLINARY PERSPECTIVES ON INTERNATIONAL LAW AND INTERNATIONAL RELATIONS: THE STATE OF THE ART 59 (Jeffrey L. Dunoff & Mark A. Pollack, eds., 2013) (surveying the institutionalist approach to international law and international relations); *see also* Victor, *supra* note 47, at 322 (arguing that treaties "are unlikely to be effective in constraining geoengineers because the interests of key players diverge and it is relatively easy for countries to avoid inconvenient international commitments and act unilaterally").

scientists, the evidence from prior modeling and laboratory experiments, the nature of the field experiment, and the robustness of domestic regulation. In the worst case scenario, it could become a source of significant international tension.

Another unfortunate scenario would be the unduly restrictive regulation of climate engineering and its research, developed in haste and based upon fears and assumptions of potential risks, without balancing such risks with climate engineering's potential to reduce the risks from climate change. The result would likely be significant net harm to humans and the environment. Considering that we, as an international community, still do not know exactly what climate engineering is, what risks its field research poses, and what we do and do not want from it, a preferred path would be the gradual emergence of norms and rules via a mixture of intergovernmental institutions and transnational communities of scientists, civil society, and other experts.[458] Fortunately, this appears to be unfolding.[459] Here, many of the bodies established by international environmental law will be particularly important.

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458. *See* Victor, *supra* note 47, at 332 ("A more effective approach to building a relevant regulatory system would concentrate, today, on laying the groundwork for future negotiations over norms rather than attempting to codify immature norms now . . . build[ing] norms from the 'bottom up.'"); *see also* William Daniel Davis, *What Does "Green" Mean?: Anthropogenic Climate Change, Geoengineering, and International Environmental Law*, 43 GA. L. REV. 901, 907 (2009) ("An internationally collaborative research program, moreover, could begin to develop international behavioral norms that would reduce the risks associated with geoengineering."); David Victor et al., *The Geoengineering Option: A Last Resort Against Global Warming?*, 88 FOREIGN AFF. 64, 66 (2009) ("Governments should immediately begin to undertake serious research on geoengineering and help create international norms governing its use. . . . Scientists could be influential in creating these norms."); David Keith et al., *supra* note 53, at 427 ("A better approach would be to build international cooperation and norms from the bottom up, as knowledge and experience develop."); Lisa Dilling & Rachel Hauser, *Governing Geoengineering Research: Why, When and How?*, 121 CLIMATIC CHANGE 553, 563 (2013) ("Over time, researchers and stakeholders could meet to assess progress in governance, identify emerging norms, and correct problems. Governance norms could spread through the sharing of 'best practices,' and the gradual institutionalization of successful ones."); M. Granger Morgan et al., *Needed: Research Guidelines for Solar Radiation Management*, 29 ISSUES SCI. & TECH. 37, 41 (2013) ("[T]here is a pressing need to develop what we will call a code of best SRM research practices."); Edward Parson & Lisa Ernst, *International Governance of Climate Engineering*, 14 THEORETICAL INQ. L. 307, 324 (2013) ("[E]arly informal cooperation on scientific research and risk assessment should seek to develop relevant norms from the ground up, by a decentralized process."); Stefan Schäfer et al., *Field Tests of Solar Climate Engineering*, 3 NATURE CLIMATE CHANGE 766, 766 (2013) ("As a starting point, [adequate governance for climate engineering research] could be achieved through the establishment of an international voluntary code of conduct.").

459. *See, e.g.*, MacCracken et al., *supra* note 129 (recommending governing principles for the conduct of climate engineering research); *see also* BIPARTISAN POLICY CENTER'S TASK FORCE ON CLIMATE REMEDIATION, *supra* note 129 (advocating open and

interdisciplinary research efforts); Rayner et al., *supra* note 129 (describing the Oxford Principles as "high-level principles for geoengineering governance").

A Critical Examination of the Climate Engineering Moral Hazard and Risk Compensation Concern

ABSTRACT

The widespread concern that research into and potential implementation of climate engineering would reduce mitigation and adaptation is critically examined. First, empirical evidence of such moral hazard or risk compensation in general is inconclusive, and the evidence to date in the case of climate engineering indicates that the reverse may occur. Second, basic economics of substitutes shows that reducing mitigation in response to climate engineering implementation could provide net benefits to humans and the environment, and that climate engineering might theoretically increase mitigation through strong income effects. Third, existing policies strive to promote other technologies and measures, including climate adaptation, which induce analogous risk compensating behaviours. If the goal is to minimize climate risks, this concern should not be grounds for restricting or prohibiting climate engineering research. Three potential means for this concern to manifest in genuinely deleterious ways, as well as policy options to reduce these effects, are identified.

Keywords: climate change, global warming, mitigation, climate engineering, geoengineering, moral hazard, risk compensation, climate economics

1. INTRODUCTION

Anthropogenic climate change poses major threats to humans and the environment. The dominant approach thus far to reducing climate risks has been efforts toward reducing annual greenhouse gas emissions (‘mitigation’). However, given the slow rate of the natural removal of additional carbon dioxide (CO_2), this can be only a long term strategy. There is also a chance that this mitigation will be suboptimal. In the meantime, emissions continue to accumulate in the atmosphere and the climatic effects of today’s emissions will not be felt for decades. As a consequence, we are already committed to an uncertain amount of climate change (Allen et al.,

2009) which may already surpass the internationally agreed-upon 2°C threshold for 'dangerous climate change' (Peters et al., 2013). Therefore, even though mitigation remains vital, society faces an unpleasant future of managing climate change. Adaptation of society and ecosystems to a changed climate has become the second set of responses to climate risks. Significant steps toward adaption may now be evident, as countries are pledging billions of dollars for it. The cash is not yet in hand, though, and like mitigation, adaptation also easily gets mired in the morass of international politics and divergent perceptions of justice.

In the context of the seriousness of climate risks and the limits of likely mitigation and adaptation, some observers are increasingly considering intentional, large scale interventions in natural systems in order to reduce climate change risks. These 'climate engineering' or 'geoengineering' proposals are diverse, and fall into two general categories. 'Carbon dioxide removal' (CDR) or 'negative emission technologies' would capture the leading greenhouse gas from the atmosphere and sequester it. Proposals include CO_2 capture from ambient air and ocean fertilization. 'Solar radiation management' (SRM) would slightly increase the reflective albedo of the earth in order to compensate for the warming effect of climate change. These techniques could include stratospheric aerosol injection and marine cloud brightening.

Climate engineering proposals have been controversial for a variety of reasons. Perhaps the most widespread concern is that it would undermine mitigation efforts. Indeed, nearly any discussion of climate engineering outside of a few scientific journals devotes significant attention to this. Taken to an extreme, this concern—typically called 'moral hazard' but more accurately 'risk compensation'—justifies a taboo, which was essentially the case (Lawrence, 2006) prior to an essay by a Nobel laureate atmospheric scientist (Crutzen, 2006), whose bona fides were beyond doubt and whose career and legacy were secure. Yet this concern has gone mostly unscrutinized (for an exceptional examination, see Hale (2012)). Although attention to climate engineering has increased in recent years, relative to mitigation and adaptation it remains on a distant tier of consideration.

This article challenges the concern that the consideration, research, development, potential for implementation and actual implementation of climate engineering would lessen mitigation and—to a lesser extent—adaptation, leading to undesirable outcomes such as greater climate change damage.[1] This will be called the climate engineering moral hazard-risk compensation (CE MH-RC) concern and, if it manifests, the CE MH-RC effect. Note that, although the CE MH-RC concern could apply to all forms of climate engineering, it is much more pronounced in those forms—particularly within SRM—which may be effective, rapid and inexpensive. The intention in this paper is to be somewhat provocative in order to encourage critical examination of widespread assumptions and assertions. It uses three approaches—empirical evidence, basic microeconomic of substitutes and existing and potential policies—to demonstrate that this concern may be overstated and hindering the development of effective climate policy. Specifically, from these approaches, I assert that

(a) there may be either no CE MH-RC effect or a reverse one;
(b) even if (a) is not the case and there is indeed such an effect, some substitution of climate engineering implementation for mitigation could provide net reduction of climate risks; and
(c) regardless of the veracity of (a) and (b), if policymakers wished to reduce any potential CE MH-RC effect, there would be little which they could effectively, realistically and ethically do.

In the process, I highlight three potential mechanisms of a genuinely deleterious CE MH-RC effect, although these mechanisms are often present in the formation of a wide range of public policies and their problematic consequences for climate change are much broader than potentially lessening mitigation. Importantly, examination of the CE MH-RC concern raises the question of what precisely are the goal and the means of climate policy. Assuming that the goal is the reduction of climate risks and subsequent damage, and that the means to this include but are not limited to mitigation and adaptation, the CE MH-RC concern should not be grounds for restricting or prohibiting climate engineering research, and responsible climate engineering research should be encouraged. However, there are some policy options to address and reduce the potential deleterious CE MH-RC effects.

[1] This is intended to be a broad definition with an emphasis on efficiency concerns (per Hale (2012)). Below I try to incorporate what Hale calls responsibility and vice considerations.

2. MORAL HAZARD, RISK COMPENSATION AND THEIR EMPIRICAL EVIDENCE

The first approach is to examine existing empirical data in order to see whether it implies a probable CE MH-RC effect. Moral hazard and risk compensation, which are the two existing categories of analogous human behaviour, will be examined in general. The former is the term that has most often been used to describe the CE MH-RC concern, although the latter is a closer fit. In each case, existing empirical evidence will be briefly reviewed. This is drawn from the disciplines which developed the terms: for moral hazard, behavioural economics of insurance; for risk compensation, behavioural psychology of risk and safety. Then the existing but limited empirical evidence for the potential CE MH-RC effect will be summarized. Note that this section describes responses of individuals whereas climate engineering is a matter of collective decision-making. Consequently, its actual consideration, research and development could yield distinct results.

Moral hazard

Moral hazard is a socially inefficient increase in risk-taking by one party once another party absorbs some of the potential negative consequences of the first party's actions, typically through an insurance-like agreement between the parties and typically without the latter party's full knowledge of this increase. The term originated in insurance economics to indicate an increase in risky behaviour by the newly-insured. Its negative connotation is a vestige of its original meaning, which was limited to intentional actions by 'unscrupulous' insurees (Black, 1910: 563). With the rise of more theoretically rigorous economic studies in the mid-twentieth century, the concept was broadened to include any increase in risk-taking by insurees (Pauly, 1968). This was then seen as a rational but possibly subconscious response to altered incentives. Now, moral hazard has been further generalized to the principal-agent problem in which the agent who creates risk has greater information regarding her actions than the principal who bears the risk (Stiglitz, 1983).

Although moral hazard seems logical and has been supported by modelling, there is not agreement as to its actual magnitude due to several challenges in empirical work (for a review, see Cohen and Siegelman (2010)). Most importantly, the problem is one of information asymmetry, which makes research inherently difficult: if the principal cannot obtain certain information regarding the agent's behaviour, then often researchers cannot as well. Another challenge is how to distinguish among three different behaviours by insurees which each lead those with greater insurance to file more claims, which is typically the actual observable event. The first of these behaviours is the increase in risk-taking after obtaining or increasing insurance. This is more accurately called *ex ante* moral hazard and is the one most relevant to the CE MH-RC concern. Second, *ex post* moral hazard is when an insuree, after increasing his coverage, files more or greater insurance claims while his risk-taking remains constant. Third, adverse selection is when those who know beforehand that they present more risk will choose to obtain more insurance. A further challenge to obtaining empirical evidence of *ex ante* moral hazard is that insurers undertake steps to reduce it, such as monitoring insurees and sharing risk with them through deductibles, co-payments and coverage limits. Finally, there are other behaviours, some of which may remain unknown, which further confound evidence of *ex ante* moral hazard. For example, obtaining medical insurance may expose insurees to information regarding the benefits of eating healthy, resulting in them *reducing* their risky behaviour.

Therefore, while numerous studies find that individuals with more insurance file more and larger claims, the majority of these studies do not (and generally cannot) distinguish *ex ante* moral hazard from adverse selection and especially from *ex post* moral hazard.[2] One review of several forms of insurance concluded that 'This literature identifies a moral hazard effect in some contexts but not in others' (Cohen and Siegelman, 2010: 72). In the best-examined field, that of medical insurance, 'there are theoretical reasons to believe that health insurance coverage may cause a reduction in prevention activities, but empirical studies have yet to provide sufficient evidence to support this prediction' (Dave and Kaestner, 2009: 369). Research into automobile insurance is just now beginning to try to tease apart *ex ante* moral hazard; initial data indeed supports at least its existence (Abbring et al., 2008). As a final example, the case of workers' compensation is muddled, in part because three parties are involved: the insurer, the employer and the employee. A recent study found some support of *ex ante* moral hazard among workers, but this seemed to be more than compensated by greater safety measures taken by the employer

[2] For reviews of insurances such as annuities, automobile, crop, health, housing, life, and long-term care, see Chiappori and Salanié (2013) and Cohen and Siegelman (2010). See also the examples of automobile repairs (Hubbard, 1998), deposit insurance (Gropp and Vesala, 2004), international lending (Dreher and Vaubel, 2004), public bailouts of banks (Nier and Baumann, 2006) and unemployment insurance (Chetty, 2008).

in order to reduce her costs (Guo and Burton, 2010). Outside of insurance, other manifestations of *ex ante* moral hazard—such as mutual defence treaties (Benson, 2012), foreign aid (Bräutigam and Knack, 2004), humanitarian intervention (Kuperman, 2008) and financial investments (Stiglitz, 1983)—can be theorized and perhaps modelled but are even more difficult to confirm empirically.

Risk compensation

Risk compensation is an increase or decrease in risk-taking once an individual perceives that risk to be lower or higher, respectively. It relies on a model of human behaviour in which people balance the advantages and disadvantages of risk-taking. If some exogenous change such as a new regulation or technology alters the perceived risk of an activity, then individuals will compensate. It differs from *ex ante* moral hazard in that the increase in risky behaviour is not due to its negative consequences being transferred onto another party, and there is consequently no information asymmetry. However, like *ex ante* moral hazard, it can be considered to be a rational, although perhaps subconscious, response to changed incentives.

Empirical evidence of risk compensation is mixed, with studies producing a wide range of rates of offsetting behaviours. The best studied field is automobile safety devices and rules, such as seat belts, road lighting and vehicle safety inspection. Early work found that although seat belt laws reduced driver and occupant fatalities, they led to more dangerous driving as evidenced by increases in accidents with pedestrians and bicyclists (Peltzman, 1975). More recent research has shown much smaller effects, with one study concluding that 'If anything, these laws and the accompanying increase in belt use result in safer driving behaviour…. Overall, seatbelt laws and the higher belt use these laws induce do not increase nonoccupant risk exposure' (Houston and Richardson, 2007: 933). Similarly divergent results have been observed in the cases of children and sports protective equipment (McIntosh, 2005; Pless et al., 2006), bicycle and snowboard helmets (Fyhri et al., 2012; Scott et al., 2007), vaccines and condoms to prevent AIDS/HIV and other sexually transmitted diseases (Brewer et al., 2007; Eaton and Kalichman, 2007) and hypertension drugs (Steptoe and McMunn, 2009). Another notable area of debate is harm reduction efforts in use of alcohol, tobacco and illicit drugs (Ritter and Cameron, 2006). Importantly, the risk compensation literature does not indicate a net increase in harm due to the offsetting behaviour, but instead only a smaller net reduction of harm than would be expected from the initial change alone.

In another similarity with moral hazard, these data are uncertain because reliable empirical studies of risk compensation are difficult. In an experimental setting, manipulating research subjects' risk perceptions is challenging, and may raise ethical constraints (Underhill, 2013). Outside of the laboratory or clinic, the offsetting behaviour can be difficult to measure and/or may be confounded by other variables. For example, bicycle helmet laws may lead to a selection effect wherein those who bike more slowly yet helmetless are deterred from biking, leaving behind those who bike for speed while helmeted (Fyhri et al., 2012). There could also be counteracting information effects, in which the perception of safety equipment serves as a reminder of a risk's seriousness, leading to *more* cautious behaviour.

Debates over certain policies which may have risk compensation effects are sometimes muddled by commentators' normative commitments. This is particularly the case with behaviours which are condemned by some as immoral, such as non-marital sex and illicit drugs. Some observers assert that even though policies such as human papillomavirus (HPV) vaccinations, prostitution decriminalization and clean intravenous needle exchanges may reduce harm, such steps would 'send a wrong message' and lead to an increase in the condemned behaviour. These situations are typically disagreements as to the policy goal. To some, the goal is to reduce certain tangible harms, while to others it is to reduce the occurrence of the morally condemned behaviour. This disagreement will be revisited below.

Empirical evidence for climate engineering moral hazard and risk compensation

The case of a potential CE MH-RC effect is even more uncertain than the investigated examples of moral hazard and risk compensation, because climate engineering is not actually being used yet and because the 'actor' in question is global society, behaving collectively with intergenerational impacts. Although the term 'moral hazard' is used more often for climate engineering, risk compensation fits better although still imperfect (Keith, 2013; Lin, 2013). In order for climate engineering and its research to present moral hazard, then risks would need to be consensually transferred to another party who has inferior information as to the behaviour of the risk-taking party.[3] If climate engineering research and development were to reduce mitigation, then this may transfer some risks to future generations, but future generations would also be the ones to benefit by having greater knowledge about climate engineering and perhaps the additional option to deploy it. It remains unclear whether these together would result in a net increase in their climate risks. Furthermore, future generations have not (and cannot) consent, and the crux of the CE MH-RC concern is not that the present generation has greater information about its behaviour than future ones do. In contrast, with risk compensation, risks to the actor are exogenously reduced, often through a technological intervention, which in turn impacts risk perception and behaviour. Models thus far do indicate that climate engineering could provide a reduction of risks from climate change[4], although some risks would be transformed in type (for example, from changes primarily in temperature to changes primarily in precipitation) and to different populations.

There are only a handful of opinion studies of climate engineering, and just five of these have implications for the CE MH-RC concern.[5] Although each has limitations, all point toward a non-existent or even reverse CE MH-RC effect. First, the Royal Society of London convened focus groups, which indicated that

> rather than presenting a 'moral hazard' issue, the prospect of geoengineering could galvanise people to act, and demand action, on greenhouse gas emission reductions. Although participants were generally cautious, or even hostile, towards geoengineering proposals, several agreed that they would actually be more motivated to undertake

[3] Actual climate engineering implementation may transfer risks onto others by, for example, changing precipitation patterns, and those who would choose to research and implement it may, in fact, have greater information than those who would bear the increased risk. However, as noted, the transfer of risk would neither be made socially inefficient by this information asymmetry, be part a consensual insurance-like agreement, nor necessarily be socially inefficient. At the same time, if anything, climate change itself presents a similar dynamic in that those whose actions create the risk—that is, mostly wealthy countries in the past and present—transfer those risks onto others—mostly poor countries in the future—and thus suboptimally mitigate (Samson et al., 2011). Andrew Parker (2014, personal communication) speculates that this dynamic could fuel a form of climate engineering moral hazard in which wealthy countries which presently feel insulated from climate change risks will insufficiently research climate engineering, in the process leaving vulnerable countries exposed to greater climate change risks.

[4] The Intergovernmental Panel on Climate Change recently reported that 'Models consistently suggest that SRM would generally reduce climate differences compared to a world with elevated greenhouse gas concentrations and no SRM' (Boucher et al., 2013: 575). See also Kravitz et al. (2014b).

[5] In some studies, respondents expressed a CE MH-RC concern, but this implies nothing as to whether these concerns are warranted.

mitigation actions themselves (such as reducing energy consumption) if they saw government and industry investing in geoengineering research or deployment (Shepherd et al., 2009: 43).

Second, a public dialogue organized by the UK's Natural Environment Research Council found evidence 'contrary to the "moral hazard" argument that geoengineering would undermine popular support for mitigation or adaptation' (IPSOS Mori, 2010: 2). Third, an opinion survey of residents of Canada, the UK and the US produced a moderate degree of opposition (a mean of 2.07 on a scale of 1 to 4, where 2 is 'somewhat disagree') to the statement 'Solar Radiation Management should be used so we can continue to use oil, coal and natural gas' (Mercer et al., 2011: 5). Fourth, in an experimental survey, some respondents were exposed to information about climate engineering, while others were not. 'Contrary to the "moral hazard" effect… subjects in the geoengineering condition did not become sanguine about climate change risks. Indeed, on the whole, they displayed *more* concern over climate change than ones in the control condition' (Kahan et al., 2014: 15). Finally, a public discussion group in the UK found that 'No-one saw the benefit of geoengineering without mitigation' (Integrated Assessment of Geoengineering Proposals, 2014: 3).

3. BASIC ECONOMICS OF SUBSTITUTES

The second approach to examine the CE MH-RC concern is through the basic economics of substitutes. Suppose that global society is simultaneously a consumer and a producer of various responses to climate change risks. These will have costs which increase for each additional unit 'purchased' (or better stated, 'invested in') because society would try to begin with the least expensive actions before moving to the more expensive ones. This gives an upward-sloping marginal cost curve. In comparison, the shape of the marginal benefit (or utility) curve is less certain: it is often assumed to be upward-sloping, but it may be horizontal on average, in that the damage averted by reducing warming from 5°C to 4°C may be equivalent to that averted from 1°C to 0°C. Future costs and benefits are included and discounted, in that they are reduced by a compounding rate in order to reflect opportunity costs and the preference to have benefits sooner and to incur costs later.[6] This yields single marginal cost and marginal

[6] Although discounting is widely accepted, intergenerational discounting is somewhat controversial, even though its assumed value is perhaps the most important variable in climate economics. See Nordhaus (2007).

benefit curves using present values, even though the costs and benefits which will actually occur at various times. Furthermore, in each case, the curves can incorporate other positive or negative effects. For example, mitigation will also reduce other forms of environmental damage, and adaptation will also make society more resilient to natural disasters. A world with elevated atmospheric CO_2 and SRM climate engineering may have higher crop yields (Xia et al., 2014), but precipitation patterns would change (Kravitz et al., 2014b), possibly in harmful ways. These benefits and costs could even include social and political effects, such as the potential militarization of SRM climate engineering and its need to be sustained for a long time, as well as aggregate normative preferences, such as the beliefs that we should minimize human interference in the natural world and that it is better to address a problem closer to its cause.[7] It is important to note that these curves remain uncertain; they could have greater or lesser slopes and could be highly nonlinear. For now, let us maintain four simplifying assumptions: (1) that mitigation is the only possible response to climate risks; (2) that decisions are made by a single, omnipotent benevolent decision-maker; (3) that the decision-maker is omniscient; (4) that preferences of various groups of people coincide; and (5) that decision makers are rational. With this single response option, society invests in mitigation until an optimum, efficient quantity, where the additional cost of one more unit equals the additional benefit of that unit.

Now the first four assumptions can be removed stepwise, the first of which is to now consider multiple responses to climate risks. After the introduction of a second response, the imperfect substitute of climate engineering implementation, the marginal benefit of mitigation will decrease because some desire to reduce climate risks will have been met through climate engineering. As a result, the quantity of mitigation will also decrease. However, the net benefit (which includes and is most likely dominated by the reduction of climate risks) will increase. After all, if the net benefit *didn't* increase—which could be the case if all the incorporated secondary costs caused the optimal amount of climate engineering to be zero or less—then there would have been no investment in climate engineering implementation, given the current assumptions. Because the benefit curves for both mitigation and climate engineering incorporate all effects and normative preferences, one cannot simply state that mitigation is the preferred

[7] This paper adopts a consequentialist approach, and does not directly address deontological ethics. However, here I attempt to incorporate individually held normative preferences. This implies that those who hold these preferences would be willing to pay for them in terms of greater damage to humans and the environment.

option. Under this, any reduction in the quantity of mitigation after the introduction of climate engineering implementation is both rational and net beneficial to humans and the environment.[8]

In reality, there are at least four top-level response categories: mitigation, climate engineering, adaptation and suffering climate change damages. The last of these is not purchased but instead manifests as a reduction in economic activity. Climate engineering implementation would decrease investments in mitigation and adaptation through substitution, and would decrease climate damages through its primary intended effect. At the same time, because climate engineering implementation is expected to have very low financial costs[9] while those of mitigation, adaptation, and climate change damages will be great, this will liberate some of society's financial resources, some of which could be used for mitigation.[10] Thus, there would be counteracting effects of climate engineering implementation on the amount of mitigation: a substitution effect, described in the previous paragraph, which would decrease it, and several income effects, described here, which would increase it. It is theoretically possible that climate engineering implementation could increase mitigation through dominant income effects.[11] These income effects would be stronger as the costs of mitigation, adaptation, and climate change damages approach a greater portion of total economic activity. However, these are each currently estimated to be only a percent or two of economic activity. On the other hand, they might turn out

[8] Climate engineering as a partial or imperfect substitute for mitigation has also been discussed by Barrett (2008); Bickel and Lane (2010); Emmerling and Tavoni (2013); Goeschl, Heyen and Moreno-Cruz (2013); Moreno-Cruz and Smulders (2010); Moreno-Cruz (2011) and Rickels and Lontzek (2012).

[9] Estimates for the direct financial costs of implementation for the most effective yet inexpensive proposed climate engineering method, stratospheric aerosol injection, are on the order of a few to tens of billions US dollars annually (McClellan et al, 2012). In terms of climate economics, this is 'essentially costless' (Nordhaus, 2013: 153). The costs of mitigation, adaptation, and climate change damages are each orders of magnitude greater.

[10] An income effect is more prominent if the good in question is necessary and as it accounts for a greater portion of the consumer's budget. It has been empirically observed to dominate the substitute effect in the case of, for example, dietary staples among poor consumers (Jensen and Miller, 2008).

[11] As a notable aside, other studies have modelled how climate engineering could lead to an increase in mitigation. Millard-Ball (2012), Moreno-Cruz (2011) and Urpelainen (2012) each considered a case in which countries are asymmetrical. Countries which could be harmed by the negative secondary effects of climate engineering would increase mitigation or be more likely to participate in mitigation agreements in order to reduce or prevent implementation of climate engineering other countries. Goeschl et al. (2013) found that a present generation which researches and develops climate engineering could simultaneously increase its mitigation level if it believed that future generations would have a strong bias in favour of climate engineering implementation. Such expected bias could be due, in the future, to (1) decision makers deploying SRM climate engineering as a 'quick fix' in the face of a 'climate emergency', (2) the presence of an influential lobby supportive of implementation or (3) a change in preferences if climate engineering became normalized.

to be higher, and one can imagine a scenario in which voters endorse setting aside only a certain percentage of society's income for climate purposes, which would increase the relative importance of the income effect. Nevertheless, the possibility of these multiple income effects actually dominating the substitution effect seems unlikely.

Lifting the second assumption transfers decision-making from a single decision-maker to numerous states which pursue their self-interests and can negotiate with each other in various forums. Let us examine in some depth the resulting effects on each of the three primary responses to climate change risks. First, mitigation presents a global, transgenerational collective action problem. In a hypothetical world of homogenous states, the benefits of each country's costly mitigation are diluted across the globe, causing them to each mitigate suboptimally. This is the classic underproduction of a public good. In the real world, those countries that are better positioned to mitigate (i.e. the industrialized countries) happen to be generally less vulnerable to climate change, exacerbating this underproduction. Moreover, the costs are borne now and the benefits reaped later, whereas political decision makers lack necessary incentives for this transgenerational investment. Barring unprecedented levels of international trust, self-sacrifice and enforcement in international cooperation, mitigation will be very suboptimal. Second, although adaptation is, for the most part, not a collective action problem, it too will likely be under-provided because the more vulnerable developing countries have less capacity to adapt. Optimal adaptation will require enormous and politically unpopular international wealth transfers from the industrialized ones to the developing ones. Thus, independent of climate engineering, adaptation and especially mitigation will be significantly suboptimal in a world of many countries.

The effect of multiple decision makers on climate engineering implementation will depend on its form. CDR is much like mitigation, and will follow a similar pattern with the magnitude of its underproduction dependent on the various techniques' costs, risks, and capacities. The case of SRM varies by the method's specific scale of impact. At one extreme, it could hypothetically be implemented locally.[12] Each country would provide for its own SRM at

[12] Localized SRM is offered here primarily as a theoretical exercise. Current assessments of proposed SRM methods show them to be either inexpensive and global (e.g., stratospheric aerosol injection) or expensive and potentially localized (e.g. surface albedo modification). Some researchers are presently discussing limited seasonal and latitudinal variation (MacMartin et al., 2013; MacCracken, 2009; Modak and Bala, 2014). In this paragraph, assume that an inexpensive, effective, local SRM method becomes available in the future.

its locally optimal level, with some positive and negative side effects for other countries. Negotiations between countries for payments could lead to compensation for victims of negative side effects, to reimbursement for positive effects, or to some other agreement to adjust the magnitude of local SRM climate engineering. In this situation, SRM would be provided at a level close to its optimum, but probably somewhat higher due to uncompensated negative externalities. At the other extreme, SRM could be completely global, with no capacity for local optimization. In an ideally cooperative world, countries would agree upon a level of SRM which maximizes total net benefits with side payments to compensate any losers, or—barring that—upon a level which would maximize total net benefits without leading to net harm for any country (see Moreno-Cruz et al., 2012; Kravitz et al., 2014b). In reality, any negotiations would occur among states with diverse levels of power, interests and capabilities. Considering its low expected financial cost, and assuming that countries may increase but not decrease the intensity of SRM, the amount of global SRM might be determined by the country that preferred the highest SRM intensity while possessing sufficient international power and influence to withstand any retaliation or reputational damage from those which preferred a lower intensity.[13] Assuming no correlation between countries' power and SRM preference, SRM climate engineering in this scenario would then be over-implemented, the magnitude of which would depend upon the degree of alignment among countries' SRM preferences. One study modelled the preferred intensity of global SRM for 22 different regions (Ricke et al., 2013). The highest preferred SRM intensity among the regions was approximately 20% greater than that of the lowest. This general alignment among regions implies that, in the world of selfish 'great powers' described above, global SRM climate engineering implementation is likely to be overproduced, but not by a very large amount. In reality, SRM intensity will likely be less extreme through technical measures, such as optimization by latitude (MacMartin et al., 2013; MacCracken, 2009; Modak and Bala, 2014) and through social measures, such as implementation through multinational coalitions (Ricke et al., 2013).

Therefore, the inclusion of multiple decision makers leads mitigation and adaptation to be suboptimal, independent of climate engineering. In the presence of climate engineering

[13] Weitzman (2013) calls this a 'free driver externality'.

implementation, these two might be somewhat more suboptimal while SRM climate engineering may be slightly over-implemented.

The third assumption to remove is that of omniscience. Thus far, I have assumed that decision makers knew the shapes of the marginal cost and marginal benefit curves for each action. As noted above, climate science and economics are uncertain. Both mitigation and SRM climate engineering pose uncertainty, some of which can be reduced through research and some of which may remain irreducible. As the reality of climate change and our responses to it unfolds, decision makers can adjust policies as they learn more about the consequences of previous actions.

The implications of uncertainty for mitigation and SRM climate engineering are not equal. The latter poses greater uncertainty both because there has been much less research to date, and because it relies upon intentional interventions in a highly complex system which has already been subject to other (unintentional) interventions. In contrast, mitigation has been studied for decades, and its irreducible uncertainty is lesser because it would reduce interventions in complex climate systems (although it would increase interventions in complex economic systems). Assuming that society is risk averse, decision makers should be willing to increase mitigation and to decrease climate engineering relative to their risk-neutral optimal levels. This would result in greater financial costs and environmental damage, but this does not imply that such risk aversion is irrational.

As research reduces the uncertainty for a given climate change response option, its expected costs, benefits and optimal amount often change. That is, later research may yield results contrary to initial expectations and preliminary research. Again, this has different implications for mitigation and climate engineering. Because researchers have been refining the costs and benefits of mitigation for decades, it seems unlikely that society would now aim for an optimal mitigation level which later mitigation research reveals to be dramatically different from optimal. In contrast, future climate engineering research may point toward an optimal level which is indeed dramatically different from what we now believe. Because the expected optimal level of mitigation is influenced by the expected optimal level of climate engineering via imperfect substitution and possible income effects, this creates the first of three potential deleterious MH-RC effects which this paper identifies. If (1) the initial expectations of climate engineering implementation were highly positive, (2) this reduced mitigation via expectations of a beneficial substitution effect and (3) later research yielded more negative results, then net climate risks would increase (See Moreno-Cruz and Smulders (2010)). However, the reverse could be true as well, in which an excessively pessimistic view of climate engineering would hinder its research and development, also increasing net climate risks. Regardless, all these scenarios call for further research.

Furthermore, mitigation and SRM climate engineering differ in how decision makers learn from and respond to the effects of their policies. In both cases, decision makers may aim for a level which they believe to be optimal but, due to lingering uncertainty, only after implementation learn to be significantly different from than optimal. In the case of mitigation, because climate change and its damages lag for decades behind the greenhouse gas emissions which cause them, the benefits of mitigation will also lag. Furthermore, mitigation itself—new technologies, policies, infrastructure, agricultural practices, ecosystem management practices, etc—is slow to implement. Once decision makers learn more about the magnitude of climate change and its damages, as well as about the revised level of optimal mitigation, excessive or insufficient mitigation cannot be rapidly corrected. In contrast, the intended effects of SRM climate engineering implementation would be felt on a relatively short time scale. If society were to implement a level of SRM which it later learned differed significantly from optimal, then this level could be adjusted upward or downward relatively rapidly, at least with the most widely discussed SRM methods which appear to be effective and inexpensive, such as stratospheric aerosol injection and marine cloud brightening (Kravitz et al., 2014a). Of course, in the meantime, the costs of insufficient or excessive SRM would be borne by humans and the environment. Although the SRM intensity could be adjusted relatively quickly to respond to global temperatures, the observation and attribution of some secondary effects of SRM climate engineering implementation, such as precipitation changes, could require many years, and any corrections would be subsequently delayed.

Finally, let us remove the assumption that all people have similar preferences. This leads to the last two potential deleterious CE MH-RC effects. For one thing, the preferences of decision makers and the broader population may not coincide. For example, they may have different discount rates, magnitudes of risk aversion, preferences for maintaining a more natural world, and preferences for addressing a problem closer to its source. They could also live in different locations and thus give different weight to particular effects of climate change and climate policies. That is, the personal costs and benefits for the various climate response options may differ between the two groups. There is therefore a risk of a genuine bias if decision makers prefer a higher level of climate engineering and a lower level of mitigation relative to the genuine population. Of course, the reverse may be true.[14] The third and final potential deleterious CE MH-RC effect could arise if there were temporal misalignment of preferences. If earlier generations were to prefer a higher level of climate engineering and a lower level of mitigation relative to future generations, then the results could be suboptimal. Again, the reverse may turn out to be the case.

To summarize, this section's simple economics of substitutes indicates that, even if climate engineering were to reduce mitigation, then its implementation could still provide net benefits through substitution. This conclusion continues to hold when considering several responses to climate change risks and many independent decision makers. Through multiple income effects, it is theoretically possible that climate engineering implementation could even increase mitigation. The relative impact of uncertainty is less clear, in part due to lesser current knowledge regarding climate engineering relative to that of climate change and mitigation. On the other hand, the response times of mitigation, adaptation and SRM climate engineering implementation indicate an advantage for the latter in response to learning. This section identified three potential deleterious CE MH-RC effects: (1) inaccurate initial expectations for mitigation and especially for climate engineering; (2) the preferences of decision makers may not coincide with those of the general population; and (3) the preferences of earlier generations may not coincide with those of later generations. Each of these could decrease or increase the level of mitigation with respect to its optimal level.

4. POLICY OPTIONS

Assuming that policy makers wished to reduce any potential CE MH-RC effect, independent of whether their concerns were warranted, then what could they do? We can first examine policies in other areas with *ex ante* moral hazard or risk compensation. The former is caused by information asymmetry between a principal and an agent regarding the risky behaviour of the agent. One response is for the principal to adopt policies which reduce the information

[14] Although it is easy to portray decision makers as being captured by powerful wealthy interests who favor continued greenhouse gas emissions, note also that aggressive mitigation would hinder economic development in poor countries.

asymmetry. For example, insurers offer lower rates if insurees demonstrate that they behave in certain low-risk ways. However, as discussed above, information asymmetry is not the problem with the CE MH-RC concern. Another response to *ex ante* moral hazard is policies wherein the insuree shares some risk, such as through deductibles and co-payments. Although *ex ante* moral hazard is a weak analogy, the suggestion that the present generation should *increase* its exposure to climate risks is considered further below.

Policies regarding risk compensation are more instructive, although as noted, imperfect. Here, the technology or the regulation which induces the risk compensation is generally promoted or required because it leads to a net decrease in harm, despite the compensating behaviour. In the best-studied case, people drive automobiles more riskily with seat belts, air bags and improved lighting, and thus cause slightly more accidents. However, these safety devices are promoted or required because they lead to net reductions in injuries and fatalities. The mirror-image of this is when people drive more carefully when they are intoxicated or use a mobile telephone, behaviours which are discouraged or prohibited because they increase harm despite the more careful driving. After all, the reduction of injuries and fatalities (balanced with rapid transportation) is the goal of automobile safety policies; encouraging cautious driving is merely one means to that end. Some economists have made a tongue-in-cheek proposal that, if the goal were indeed to be cautious driving, then a spike in the centre of the steering wheel pointed at the driver would be preferable to a seat belt (McKenzie and Tullock, 1981: 40). Other examples of risk compensation are promoted by similar policies or norms in the cases of sports safety equipment, gun storage and public health measures. Furthermore, large public investments are made in developing treatments for medical conditions which are caused by lifestyle choices, such as lung cancer and type 2 (adult onset) diabetes. These approaches are consistent with the simple economics described above, in which the introduction of a substitute might reduce cautious behaviour but results in increased net benefits.

A notable exception to this pattern is when the behaviour is condemned by some as immoral. As noted above, harm reduction policies with regard to non-marital sex and illicit drugs are often opposed not because of their likely effect on tangible harms (although opponents sometimes also try to make that argument) but because they would likely increase the occurrence of the condemned behaviour. Here, the disagreement is over the policy goal. If the goal is to reduce the tangible harms, then these harm reduction policies are beneficial. However, if the goal is to reduce the condemned behaviour, then the measures are opposed because they would lead to an increase in the behaviour's occurrence. Indeed, from this perspective, the risks of the behaviour should intentionally be kept high.

These examples shed light on the CE MH-RC debate. If the goal of climate policy is to minimize climate risks to humans and the environment, then climate engineering should be seriously considered, at the present time through research. However, if its goal is mitigation itself, then climate engineering and its research should be taboo.

Those who wish to restrict or forego climate engineering research due to the CE MH-RC concern should reflect on the history and current status of adaptation in the climate change discourse. In the 1990s, there was widespread concern that consideration of and research into adaptation to a changed climate would hinder mitigation. It was called 'an unacceptable, even politically incorrect idea' because, among other reasons, it 'could make a speaker or a country sound soft' on mitigation (Burton, 1994: 14). Along similar lines, then-US Vice President Al Gore initially called adaptation 'a kind of laziness, an arrogant faith in our ability to react in time to save our skin' (Gore, 1993: 240). During this time, 'the first obstacle to adaptation is reluctance to contemplate it' (Waggoner, 1992: 146), and it 'was viewed with the same distaste that the religious right reserves for sex education in schools. That is, both constitute ethical compromises that in any case will only encourage dangerous experimentation with the undesired behaviour' (Rayner and Thompson, 1998: 292). However, adaptation is now a second widely accepted category of responses to climate risks. This change was due to the facts that some climate change cannot be avoided and that the burdens of it will fall largely on the world's poor. Gore now admits that he was 'wrong in not immediately grasping the moral imperative of pursuing both policies [mitigation and adaptation] simultaneously, in spite of the difficulty that poses' (Lind, 2013). Although there cannot be a 'control group' in order to compare the climate change discourse with and without the consideration of adaptation, it is difficult to argue that the mainstreaming of adaptation has significantly reduced mitigation. It is unclear how and why climate engineering is fundamentally different from adaptation in this regard.

Let us concede for a moment that policies should indeed strive to reduce any CE MH-RC effect, regardless of whether the concern is warranted. At this point in time, the issue is whether and how to discuss and research climate engineering.[15] The assertion that the taboo against publicly discussing climate engineering should be reinstated or that climate engineering research should be severely restricted (or at least not be publicly funded) is an argument that climate engineering constitutes a form of 'forbidden knowledge' and is, at its core, a case for sustained wilful ignorance in the face of large risks to humans and the environment (see Rayner, 2014). This is even more so due to the uncertainty of climate change. Climate sensitivity may turn out to be much higher than expected; harm to humans and the environment from climate change may be greater than expected; the capacities of ecosystems and society to adapt may be much lower than expected; and mitigation and adaptation may remain too low. In these events, climate engineering could be much more beneficial than it is now understood to be because of the possibilities of rapid and unilateral implementation, as described above.[16] If anything, prohibiting or restricting climate engineering research would increase the likelihood of a hazardous CE MH-RC effect due to lingering but unsubstantiated expectations of climate engineering's potential to reduce climate risks, and would lead to future decision-making to be based upon a thinner knowledge base.

Recently, papers by two legal scholars proposed policies which would attempt to reduce any CE MH-RC effect (Lin, 2013; Parson, 2013). Some of these proposals, such as international deliberation regarding the circumstances under which climate engineering would be warranted, public outreach to counter perceptions that climate engineering would 'solve' climate change and accountable oversight (Lin, 2013) would aim to reduce two of the potential deleterious CE MH-RC effects cited in the previous section, those due to high expectations and to different preferences between decision makers and the general population. Other norms and rules, such as open publication of results and no patents on SRM technologies, could also reduce these potential negative effects (see Bipartisan Policy Center Task Force on Climate Remediation Research, 2011; Leinen, 2011; Rayner et al., 2013; Solar Radiation Management Governance Initiative, 2011).

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[15] This is not to say that *how* climate engineering is considered and researched will have no impacts on how it might be implemented and on mitigation.

[16] Of course, the opposites may turn out to be true, and knowledge of climate engineering would have less value. I emphasize its potential value in the event of greater climate damage because people tend to be risk averse and because SRM climate engineering could be rapidly implemented.

More ambitiously, the authors propose that climate engineering research or implementation could be contingent upon whether states meet mitigation targets.[17] While this logic from our current vantage point may appear wise, imagine if those targets are not met—which seems not unlikely assuming that the targets are meaningful—and climate engineering were then not permitted. Should—and would—global society or individual nations then forego an option which may reduce climate risks, or would such an agreement lack credibility? Other writers have posited that climate engineering should not be considered whatsoever, and among their reasons is the CE MH-RG concern (for example, see Hamilton, 2013; Winter, 2011). These are often arguments that considering climate engineering would discourage normatively desirable behaviour, but I assert that they may have mistaken the means (i.e. mitigation) for the end (i.e. risk reduction) of climate policy. Whether through linkage agreements, restrictions, or prohibitions, a denial of a potential means to reduce climate risks is equivalent to intentionally increasing risk in order to incentivize mitigation. This is analogous to the spike in the automobile's steering wheel, described above, increasing the driver's risk in order to incentivize cautious driving. More accurately, it would be like a spike in front of the passenger, as it is largely the current residents of wealthy countries who are shaping climate policy but future generations and the world's poor who will bear most of the climate change harm. It seems unwise and unethical to increase climate risks which will largely be borne by others as an assertion of mitigation's primacy or as a sort of high-stakes wager that climate engineering would never be beneficial.

An exception among these authors' proposals is the most sophisticated of Parson's (2013) proposed means to link mitigation and climate engineering. In this, he suggests that nations agree to a treaty in which those states that fail to meet their mitigation targets would be excluded from decision-making regarding climate engineering implementation. The author acknowledges its shortcomings. For example, if states' preferences for the form and intensity of climate engineering were to be closely aligned, as implied by some studies (Ricke et al., 2013), or if effective and affordable localized SRM methods were developed then they would have little incentive to participate in the agreement. Furthermore, if the mitigation requirements were quite aggressive—which appear necessary in order to significantly reduce climate change risks—then

[17] Note that Parson uses this proposal primarily as a logical stepping stone to others, which he then endorses more strongly.

powerful countries which rely on continued emissions might not participate in the treaty or fail to meet their targets, with the knowledge that they would have enough international power and influence to later implement climate engineering regardless of the agreement. Moreover, climate engineering presently remains too uncertain to serve as an effective inducement to mitigate, although this may change in the future. Nevertheless, Parson's proposal warrants further consideration.

5. DISCUSSION AND CONCLUSION

This paper has attempted to demonstrate three things. First, the empirical evidences of *ex ante* moral hazard and risk compensation in general and of a CE MH-RC effect specifically are not fully conclusive. Indeed, the limited empirical evidence thus far indicates that climate engineering could present a reverse CE MH-RC effect. Second, and independent of the first conclusion, the simple economics of substitutes suggests that, to the extent that climate engineering implementation might actually reduce mitigation through substitution, this could be rational and beneficial. In fact, it is theoretically possible that implementation could increase mitigation through strong income effects. Third, technologies and regulations which causes risk compensation—the better analogy of the two—are usually promoted. Even if policy makers wanted to reduce any CE MH-RC effect, regardless of its actual existence, restricting or prohibiting climate engineering research is likely to do net harm and would not be feasible.

In the process, this paper identified three potential mechanisms of deleterious CE MH-RC effects. First, expectations of mitigation and especially of climate engineering may differ significantly from what is later learned. Second, the relevant preferences of decision makers and those of the general population may not coincide. Third, the relevant preferences of earlier generations and of later generations may not coincide. To the degree feasible, effective and ethical, policies should be adopted which would reduce the likelihood and intensity of these mechanisms, or at least of the first two. As noted above, more and better research into all response options—including that of climate engineering—to climate change risks would more quickly reduce uncertainty and bring expectations closer to reality. Public consultation, international deliberations, accountability, transparency, and intellectual property restrictions could reduce the negative impacts of the first two mechanisms. The third possible mechanism is particularly thorny, as preferences are dynamic and are partially dependent upon the actions of previous generations (see Norton et al., 1998). In particular, the development of new technologies can have a strong influence upon future generations' preferences. The present generation makes value-laden decisions, such as trade-offs between incommensurable goods or value, in certain ways, and does not wish to be constrained to doing so exactly like previous generations would have done. Likewise, future generations presumably will not want to be constrained to doing exactly like we do. It is unclear to what extent we should attempt to influence the preferences of future generations and to what extent we should attempt to constrain the behaviour of future generations in order to reduce the likelihood that they will make choices contrary to our current preferences.

However, these three potentially problematic mechanisms are not limited to climate engineering, climate change, or even the environmental but instead are present in many—and perhaps all—significant social undertakings, ranging from the relatively mundane (e.g. land use planning) to the extraordinary (e.g. war). Similarly, even when considering only the climate engineering discourse, these three mechanisms point to challenges which are broader than the CE MH-RC concern, such as regulatory capture, technocracy, scientism, hype, technological lock-in, and the so-called slippery slope. These challenges are not unique to climate engineering and it is not immediately evident why climate engineering policy should be held to especially high standards in these regards.

In addition, all three mechanisms could operate in manners which would increase mitigation and suppress climate engineering, even to harmful degrees. The presently expected net benefits of mitigation and those of climate engineering could be greater and lower, respectively, than actual reality. Decision makers could be more favourable to mitigation and more averse to climate engineering than the general population. Future generations could also be more averse to mitigation and more favourable to climate engineering than earlier ones. These are, to some degree, empirical matters whose answers are not obvious.

We should not assume that the CE MH-RC concern is warranted and that any substitution of climate engineering for mitigation would be negative. Even in the cases of the potential mechanisms which might cause deleterious mitigation reduction—mechanisms which go beyond the scope of the CE MH-RC concern and which are also present in many other policy choices—we should not assume that optimal mitigation is always the victim. Policy should be rationally designed and based upon the central goal of minimizing net climate risks to humans and the environment in accordance with society's preferences. Those who argue that consideration of and research into climate engineering should be restricted due to the CE MH-RC concern have the burden to demonstrate that such effects are likely and would be harmful, and that humans and the environment would be better protected by foregoing this option. Until then, this concern should not be grounds for restricting or prohibiting climate engineering research.

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The International Regulation of Climate Engineering: Conclusion

This collection of articles has explored how climate engineering, particularly its research, may be internationally regulated. Three of these considered how existing international environmental law, broadly defined, might be applied. I argued that climate engineering research and implementation, and carbon dioxide removal (CDR) and solar radiation management (SRM), should each generally be considered separately[1] and that, on the whole, existing international environmental law is favourable toward climate engineering research.[2] More particularly, with my colleague Floor Fleurke, I asserted that the precautionary principle calls for careful exploration of climate engineering's potential to reduce climate risks.[3] The other two articles were more forward-looking, and considered how future international regulation of climate engineering might and should develop. Drawing on the analogous case of nuclear power, I claimed that climate engineering is not likely to be regulated by a comprehensive binding multinational environment agreement, at least anytime soon.[4] The final paper critically examined the concern that the consideration, research, development, and potential implementation of climate engineering would hinder the abatement of greenhouse gas emissions.[5] I averred that this concern is overstated and that it should not play a central role in climate engineering policy.

The aim of this research project was to suggest components of a feasible international regulation for climate engineering, particularly for research into the more highly leveraged methods, which would balance the desire to fulfil climate engineering's potential with that to minimize its risks. This assumes, of course, that such research should indeed move forward, which I concluded in my examinations of the precautionary principle and the moral hazard risk

[1] Article 1, 'The Regulation of Climate Engineering'.

[2] Article 4, 'Climate Engineering Field Research: The Favorable Setting of International Environmental Law'.

[3] Article 2, 'Climate Engineering Research: A Precautionary Response to Climate Change?'.

[4] Article 3, 'The International Regulation of Climate Engineering: Lessons from Nuclear Power'.

[5] Article 5, 'A Critical Examination of Climate Engineering Moral Hazard and Risk Compensation'.

compensation concern.[6] At this time, one or more detailed binding multilateral agreements regulating the entirety of climate engineering seem unlikely, for several reasons.[7] Instead, as is also argued there, norms regarding climate engineering and its research must develop somewhat organically—a slow process—and then gradually become 'legalized'. I also suggest three subsequent components of a regulatory regime, which in decreasing order of confidence are an international institution, a liability mechanism, and a non-proliferation agreement.

Before moving into specifics, a handful of initial guiding principles should be considered. First, regulations have numerous, sometimes quite significant consequences, yet policymakers cannot be omniscient of these consequences. They should thus exercise caution when attempting to purposefully guide human behaviour in domains which are complex, remain partially unknown, and have high stakes. Climate engineering fits these criteria. In fact, not only do we not yet fully know what climate engineering will be like, but society remains far from a consensus regarding what we want from it. Second, law—particularly international law—is slow to change. This can be beneficial in terms of the previous exhortation for policymakers to be cautious in implementing regulation. Simultaneously, it also reinforces that exhortation, in that regulation which is later learned to be suboptimal is usually difficult to amend. Third, even in the absence of specific binding multilateral environmental agreements,[8] actions by one country which are strongly contrary to the interests of others will still be costly to the former because the latter ones can respond through reputational loss, retaliation, and possible reciprocation.[9] Thus, although unilateral global implementation of global stratospheric aerosol injection (SAI) using engineering nanoparticles from a ship on international waters may not be clearly prohibited by an existing agreement, a country which would conduct, approve, or passively permit this would face costs in the international arena which would likely be greater than the benefits it would receive from the climate engineering. Even the United States, as the world's lone superpower, would gain little, in

[6] Article 2, 'Climate Engineering Research: A Precautionary Response to Climate Change?'; Article 5, 'A Critical Examination of Climate Engineering Moral Hazard and Risk Compensation'.

[7] See text to n 90-93 in article 3, 'The International Regulation of Climate Engineering: Lessons from Nuclear Power'.

[8] See article 4, 'Climate Engineering Field Research: The Favorable Setting of International Environmental Law' for a review of relevant multilateral environmental agreements.

[9] Andrew Guzman, *How International Law Works: A Rational Choice Theory* (Oxford University Press 2008). Consider that Iran's nuclear program is probably in compliance with international law yet it still has borne retaliation and reputational costs. See Daniel Joyner, 'Iran's Nuclear Program and International Law' (2013) 2 Penn State JL Intern'l Aff 282.

large part because it is not very vulnerable to climate change in the near term.[10] At the very least, the customary international law of the prevention of transboundary risk and the mitigation of its subsequent harm would form an adequate basis for international condemnation of premature and irresponsible climate engineering implementation or large-scale research.[11] From these, I conclude that a comprehensive and detailed international agreement on climate engineering is both premature and unlikely. If such an agreement were to come into force, it could be harmful by restricting potentially beneficially research, perhaps inadvertently, while being difficult to later revise. As an alternative, it would be wise to examine what components of a gradually emerging regulatory regime would offer the greatest net benefit while remaining both feasible and adaptive to future developments.

1. NONBINDING NORMS

Throughout the articles collected here, I have emphasized the importance of nonbinding norms.[12] The development, specification, and institutionalization of nonbinding norms are the most important first step toward the international regulation of climate engineering and its research. The advantages include that they can be relatively rapidly developed, adapted, and modified in the face of changing circumstances; that their generality allows appropriate application in diverse settings; and that, through their bottom-up development in nonstate forums, they can effectively capitalize upon expertise while avoiding some limitations of electoral politics. Furthermore, the negotiation process toward norms can help establish consensus on some matters of debate while deferring on others, whose resolution may remain challenging. Finally, norms can be used as the starting point for developing future binding rules-based regulation.

[10] The US is ranked as the 13th most secure among all countries (using 2012 data) in a combined metric of vulnerability to and readiness for climate change. University of Notre Dame Global Adaptation Index <http://index.gain.org> accessed 24 June 2014. The most feasible unilateral implementation may be from India, which is vulnerable to climate change, has relatively advanced technical capabilities, and is a nuclear power. Scott Barrett, 'Solar Geoengineering's Brave New World: Thoughts on the Governance of an Unprecedented Technology' (2014) 8 Rev Envtl Econ Pol 249. See also Joshua Horton, 'Geoengineering and the Myth of Unilateralism: Pressures and Prospects for International Cooperation' (2011) 4 Stan JL Sci Pol'y 56.

[11] See text to n 387-427 in article 3, 'Climate Engineering Field Research: The Favorable Setting of International Environmental Law'.

[12] See text to n 100-106 in article 1, 'The Regulation of Climate Engineering'; text to n 94-96 in article 3, 'The International Regulation of Climate Engineering: Lessons from Nuclear Power'; text to n 457-58 in article 4, 'Climate Engineering Field Research: The Favorable Setting of International Environmental Law'.

Two challenges to nonbinding norms should be highlighted. First, the legitimacy of nonbinding norms, particularly if they are developed outside of accountable state institutions, can be problematic. However, accountability is not the sole basis of claims to legitimacy, particularly when addressing international and technically complex challenges under globally diffused authority. For example, Gráinne de Búrca proposed that the traditional means toward legitimacy developed in the domestic setting could be compensated for in the global arena through three other categories of mechanisms: the merits of the decision makers, such as independent expertise; the qualities of the decision making process, such as transparency and protection for basic rights; and the aspects of the output, such as quality, efficiency, or general acceptability.[13]

A second problem for nonbinding norms is the difficulty of their enforcement and the potentially resulting ineffectiveness. After all, their violation generally carries no specific enforced consequence, although this is not to imply that violating nonbinding norms carries no cost. The magnitude of this enforcement challenge varies widely by the setting. Nonbinding norms will be ineffective when the regulated actor has strong incentives to violate them yet would bear little cost in doing so. For example, producers would be unlikely to consistently follow nonbinding norms proscribing known carcinogens in consumer products if the carcinogens' removal would be expensive while their effects would be delayed and of uncertain causation. However, climate engineering researchers are not traditional profit maximizers in four critical ways. First, instead of profits they pursue some mix of the generation of useful knowledge, public acclaim, and career advancement with its related income. To the extent that they strive to generate useful knowledge, it is in their interest to learn of and publicize actual or potential negative consequences of their experiments. Second, they will be vulnerable to—and most likely fear—greater regulation. Third, climate engineering researchers appear to recognize the controversial nature of their work[14] and, like nuclear power operators, will need to maintain a positive reputation and to seek a 'social license to operate,' lest they incur the wrath of restrictive regulation.[15] Fourth, they are embedded in complex networks—including peers, professional societies, publishers, funders, and domestic regulators—which can be leveraged to encourage

[13] Gráinne de Búrca, 'Developing Democracy beyond the State' (2008) 36 Colum J Transnat'l L 221, 240-246.

[14] See Jonas Anshelm and Anders Hansson, 'Battling Promethean Dreams and Trojan Horses: Revealing the Critical Discourses of Geoengineering' (2014) 2 Energy Res & Soc Sci 135.

[15] See text to n 52 in article 3, 'The International Regulation of Climate Engineering: Lessons from Nuclear Power'.

responsible behaviour. The most intimate of these is the peer network. This is particularly important because the public will unlikely clearly differentiate among climate engineering researchers. As a consequence, they will share a reputations commons and constitute a 'community of shared fate'.[16] It seems likely that inappropriate or irresponsible work by one will have significant spillover effects on them all in terms of public and political support as well as resulting regulation. Therefore, the researchers will have reduced incentives to violate norms while having strong incentives to monitor each other.[17]

There have already been steps toward the development of norms for climate engineering and its research. Three sets of principles have been drafted in recent years (Table 1). Their sources are somewhat disparate: a small group of UK-based academics, a self-organized meeting of climate engineering researchers and research advocates, and a task force assembled by a well-connected American think tank. There is significant but not complete overlap among the three sets, and there are no clear disagreements among them. Furthermore, other climate engineering reports express norms which are generally consistent with those in the three detailed sets.[18]

[16] Ibid, text to n 53-54, 81.

[17] This threat of more restrictive regulation in the context of networks of peers, nonstate actors, and state actors is an potential example of Gunningham and Grabosky's regulatory pyramid. Neil Gunningham and Peter Grabosky, *Smart Regulation: Designing Environmental Policy* (Oxford University Press 1998)

[18] See, eg, John Shepherd and others, *Geoengineering the Climate: Science, Governance and Uncertainty* (The Royal Society 2009); Science and Technology Committee, UK House of Commons, *The Regulation of Geoengineering* (The Stationery Office 2010); Solar Radiation Management Governance Initiative, 'Solar Radiation Management: The Governance of Research' (2011) <http://www.srmgi.org/report/> accessed 19 April 2013; Robert L. Olson, *Geoengineering for Decision Makers* (Woodrow Wilson International Center for Scholars 2011).

Table 1. Summary of proposed climate engineering norms.[19]

Oxford Principles	Asilomar Principles	Bipartisan Policy Center
• CE to be regulated as a public good • Public participation in decision-making • Disclosure of research and open publication of results • Independent assessment of impacts • Governance before deployment	• Collective benefit • Establishing responsibility and liability • Open and cooperative research • Iterative evaluation and assessment • Public involvement and consent	• Purpose of research: protect humans and environment from climate change and CE • Field deployment of SRM presently inappropriate • Direction for research programs based on expert advice and informed by public engagement • Importance of transparency • International cooperation • Adaptive management

The regulation of climate engineering and its research would be furthered if these norms, and perhaps others, were to be more robustly detailed and institutionalized. There is already progress on the former process. The original publications containing each set of norms included details and remaining issues for each norm. Other writers have elaborated some of them. For example, there are numerous articles on climate engineering governance prior to deployment,[20] and several recent and forthcoming ones on compensation and liability.[21] Other norms remain less clear. What might it mean, precisely, for climate engineering to be 'regulated as a public good' or in the 'collective benefit'? While there appears to be general agreement that the broader public should be involved, how might this goal actually be operationalized? Are 'public

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[19] The bullet lists are very brief summaries only. Margaret S. Leinen, 'The Asilomar International Conference on Climate Intervention Technologies: Background and Overview' (2011) 4 Stan J L Sci Pol'y 1; Jane Long and others, *Geoengineering: A National Strategic Plan for Research on the Potential Effectiveness, Feasibility, and Consequences of Climate Remediation Technologies* (Bipartisan Policy Center 2011); Steve Rayner and others, 'The Oxford Principles' (2013) 121 Clim Change 499.

[20] See eg Daniel Bodansky, 'The Who, What, and Wherefore of Geoengineering Governance' (2013) 121 Clim Change 539; Lisa Dilling and Rachel Hauser, 'Governing Geoengineering Research: Why, When and How?' (2013) 121 Clim Change 553; Edward Parson and Lia Ernst, 'International Governance of Climate Engineering' (2013) 14 Theo Inq L 307; Michael Zürn and Stefan Schäfer, 'The Paradox of Climate Engineering' (2013) 4 Global Pol'y 266.

[21] Martin Bunzl, 'Geoengineering Harms and Compensation' (2011) 4 Stan J L Sci Pol'y 69; Toby Svoboda and Peter Irvine, 'Ethical and Technical Challenges in Compensating for Harm Due to Solar Radiation Management Geoengineering' (2014) 17 Ethics Pol'y & Environ 157; Jung-Eun Kim, 'Implications of Current Developments in International Liability for the Practice of Marine Geo-engineering Activities' (2014) 2 Asian JIL 235; Joshua Horton, Andrew Parker and David Keith, 'Liability for Solar Geoengineering: Historical Precedents, Contemporary Innovations, and Governance Possibilities' (2015) 22 NYU Envtl LJ (forthcoming).

participation in decision making', 'public involvement and consent', and 'public engagement' equivalent, and are each feasible?

In contrast, there has been little movement toward the operationalizing of these norms. From the top, authoritative institutions—particularly electorally accountable ones—could endorse them. To this end, the United Kingdom House of Commons backed the Oxford Principles, with come caveats.[22] From a bottom-up perspective, professional societies, funders, and publishers could approve these norms or develop their own, in which case membership, funding, and publishing respectively could be contingent upon compliance. Finally, climate engineering researchers should consider forming their own professional society in order to refine norms, to offer membership to researchers who meet certain criteria, to condone particular research projects, and to condemn researchers and projects which are contrary to the norms.

2. AN INTERNATIONAL INSTITUTION

A second important step toward the international regulation of climate engineering and its research would be the establishment of an international institution. Such institutions are vital to global environmental governance, performing a diverse array of functions and taking a variety of forms. An international climate engineering body could have a limited set of responsibilities, both facilitating and regulating climate engineering research. These dual responsibilities would not be merely coincidence or convenience. Instead, in some instances the 'carrot' of assistance can serve to further regulation, particularly in an international, complex, and dynamic environment where a more highly legalized regulatory regime is lacking or would be ineffective.

An international climate engineering body could assume different structures, with implications for legitimacy and effectiveness. Three relevant but interrelated questions to this end are, firstly, its membership and participation; secondly, how it would relate to the bodies of the United Framework Convention on Climate Change (UNFCCC); and thirdly; how such an institution may originate. Its participants could be drawn not only from states, but also from other intergovernmental bodies, scientific organizations and professional societies, major research funders, nongovernmental organizations, and leading publishers. In order to maintain legitimacy in a potentially contested terrain, it may be preferable to distinguish states and certain intergovernmental bodies as full members with collective decision-making authority from other

[22] Science and Technology Committee, UK House of Commons (n 18), 29-33.

participating parties. Regarding the UNFCCC, on the one hand, that agreement has universal participation and its bodies are presently the leading global vehicle for internationally coordinated global responses to climate change. Constituting an international climate engineering body via the UNFCCC would endow the new organization with greater legitimacy and initial capacity, including more robust linkages with existing international institutions. On the other hand, the UNFCCC bodies and process have in some ways been arguably ineffective, in part due to the agreement's universal participation and its resulting unwieldy constituency.[23] Furthermore, they might be too strongly committed to abatement and adaptation to seriously move climate engineering research forward, causing discussions to become unnecessarily bogged down in the moral hazard-risk compensation concern.[24] In this case, a handful of countries could launch the body on their own, expanding membership as it is appropriate and effective.[25] If so, however, it would be critical to begin with diverse representation, including developing countries.

As stated above, an international climate engineering institution could have responsibilities which include both facilitative and regulatory functions. In the former it could coordinate activities both to strategically plan projects and to minimize interference among field tests; coordinate funding in order to better distribute costs; facilitate international research cooperation; foster research capacity, particularly in developing countries; and serve as a researchers' clearinghouse of international and national regulation, relevant intellectual property, and experimental results. Looking toward the regulatory side, the institution could further operationalize the norms discussed above by providing a forum where they could be detailed and gradually legalized into something more closely resembling rules; assist researchers with regulatory compliance; and ensure that all results, impact assessments, and other relevant documents are centrally and publicly available. More ambitiously, the international institution could serve as an intellectual property trustee. This could serve a facilitative function by offering

[23] See Gwyn Prins and others, 'The Hartwell Paper: A New Direction for Climate Policy after the Crash of 2009' at <http://eprints.lse.ac.uk/27939/> accessed 24 June 2014.

[24] Article 5, 'A Critical Examination of Climate Engineering Moral Hazard and Risk Compensation'.

[25] For arguments for action by a limited group of states, see Daniel Bodansky, 'May We Engineer the Climate?' (1996) 33 Clim Change 309, 319; David Victor, 'On the Regulation of Geoengineering' (2008) 24 Oxford Rev Econ Pol'y 322, 331–32; William Daniel Davis, 'What Does "Green" Mean?: Anthropogenic Climate Change, Geoengineering, and International Environmental Law' (2009) 43 Ga L Rev 901, 928–38; David Keith, Edward Parson and Granger Morgan, 'Research on Global Sun Block Needed Now' (2010) 463 Nature 426, 427; Richard Elliot Benedick, 'Considerations on Governance for Climate Remediation Technologies: Lessons from the "Ozone Hole"' (2011) 4 Stan JL Sci Pol'y 6, 7–8; Parson and Ernst (n 20), 333-34.

a pool of patents and preventing patent thickets. At the same time, this could prevent critical patents from being held by private interests. In the event that the climate engineering institution is not subsidiary to the UNFCCC, it would be in a strong position to liaise with the bodies of that treaty as well as international institutions, such as the Intergovernmental Panel on Climate Change, the Conference of Parties to the Convention on Biological Diversity, and the UN Environment Programme. For all these responsibilities, but particularly the facilitative one, a scientific committee within the institution would be warranted.

The institution should take an approach to fostering compliance which is both managerial and sanctions-oriented. A state or researcher which fails to comply with the norms or rules could receive assistance with coming into compliance while also be denied access to the institution's facilitative functions, including funding mechanisms and intellectual property. The body could also assist individual countries with complying with international obligations; help them develop and implement national climate engineering regulation; and in the event of an international dispute, offer adjudication. Finally, the international institution could serve as a forum for the development, enforcement, and modification of a possible moratorium on large-scale field experiments and climate engineering implementation, and of later multilateral agreements concerning climate engineering such as the ones discussed below.

For an international climate engineering institution with the above functions to be feasible (in the sense of likely having broad enough participation in order to fulfil its mission) only researching states need to join it, although the participation of non-researching ones would bolster its legitimacy. The facilitative functions described above would make the research more efficient and subsequently lower transaction costs among researching states and scientific groups. Assuming for now that countries would research climate engineering in order to genuinely reduce climate change risks, they too would desire that it proceed with lower risks and in line with legal norms, and would thus endorse the body's regulatory functions as well. This would particularly be the case given climate engineering's lingering controversial nature. Some observers, though, have speculated that individual countries may seek to unilaterally use—and by extension to research—climate engineering in order to pursue relative gains in the international arena.[26] If

[26] Alan Robock, '20 Reasons Why Geoengineering May Be a Bad Idea' (2008), 64 Bull Atom Sci 14, 17; Victor (n 25), 324; Davis (n 25), 926; John Virgoe, 'International Governance of a Possible Geoengineering Intervention to Combat Climate Change' (2009) 95 Clim Change 103, 115-16; Jason Blackstock and Jane Long, 'The Politics of Geoengineering' (2010) 327 Science 527, 527.

such potential relative gains were a dominant motivation, then some researching states might decline participating in an international institution due to its regulatory responsibilities and prioritization of transparency and collaboration. Several lines of evidence point away from such a likelihood. First, these researching countries may themselves also be vulnerable to the negative secondary effects of climate engineering field research. Second, modelling thus far indicates that various regions have roughly similar preferences for the level of global SRM intensity, implying that climate engineering preferences may not widely diverge.[27] Third, a country which engages in large scale climate engineering research outside internationally accepted norms and institutions runs the risk of suffering reputational and retaliatory costs. Fourth and finally, even if a country did indeed wish to later unilaterally implement climate engineering, it could still choose to cooperate internationally in responsible field research in order to minimize possible reputation and retaliatory costs.

3. LIABILITY OR COMPENSATION FOR DAMAGES

A third important component of international regulation would be a mechanism for liability or compensation for transboundary damages resulting from climate engineering field research. From a legal perspective, liability or some other compensatory mechanism would further restorative justice by compensating victims for their losses. From an economic analysis of law, which in general attempts to incentivize behaviour that would maximize net benefits, liability possesses some advantages over rules-based regulation in the case of climate engineering.[28] Most importantly, the climate engineering researchers will have much more information regarding how to minimize risks than would the government or other authoritative institution. It is indeed difficult to imagine how a regulatory authority could develop detailed rules for climate engineering field trials which would both be effective and remain relevant, given that the experiments will vary and knowledge will continuously change. At the same time, some of the strongest arguments for rules-based regulation—that individual victims may not perceive harm, that they may be unaware of its probable source, and/or that they may have inadequate incentive to take action—appear at first to apply to potential harm from climate engineering and

[27] Katharine Ricke, Juan Moreno-Cruz and Ken Caldeira, 'Strategic Incentives for Climate Geoengineering Coalitions to Exclude Broad Participation' (2013) 8 Envtl Res Lett 014021.

[28] Steven Shavell, 'Liability for Accidents' in Mitchell Polinsky and Steven Shavell (eds), *Handbook of Law and Economics*, vol 1 (North-Holland 2007).

its field research, such as harm from secondary negative effects including precipitation changes. However, these potential relative shortcomings of liability are ameliorated by two mechanisms. First, states can serve as victims as well, and will have the capacity to be aware of the harm and its probable causes and will have the incentive to take action. Second, as described above, climate engineering researchers have, to some degree, incentives to discover and communicate harm from their field experiments.

From this, I cautiously suggest a multilateral agreement wherein parties establish and contribute toward a compensation fund for victims of climate engineering research. The fund would be supported through contributions from parties to the agreement, with the relative amounts based upon some mixture of their ability to pay, their historical greenhouse gas emissions, and their potential benefit from climate engineering. Although holding the injurers liable is generally preferable to mere compensation, as this incentivizes their reduction of risk, this would not be the case here. First, the researchers will not capture the value of what they create. In this sense, the generation of knowledge through research is a public good,[29] assuming open publication of results and minimal intellectual property claims.[30] Instead, researchers' civil liability would disincentive the production of this public good, something which is generally underproduced and often publicly subsidized. Second, the potential damages could be far greater than the budgets of research groups, making them unable to pay.[31] Liability insurance, even if it were available (which is difficult to imagine), would likewise be prohibitively expensive for scientists. In principle, the authorizing state could be held liable, but this too would create perverse incentives. Given that the states which are likely to conduct climate engineering field research (i.e. the industrialized countries) are relatively less vulnerable to climate change, state liability would discourage them from participating in such an agreement and, if they were to join, discourage them from conducting public good research which might reduce climate change risks.

Claims for compensation would be bounded, in that damage must occur in a party's territory, and damages would be limited in time, amount, and forms of harm. Importantly, parties would agree to forego any other international legal recourse in the event of harm. An expert panel would review claims and, using the best available methods, assess the probability that that the

[29] Doinique Foray, *The Economics of Knowledge* (MIT Press 2004) at 113-29.

[30] These are part of the presently emerging norms. See text to n 19.

[31] Damages due to reduced precipitation could be on the order of tens of billions of euro.

research actually caused the harm. Fault would not need to be demonstrated. Awarded damages would be prorated to the probability of causation, but only above a certain minimum threshold probability in order to discourage frivolous suits.[32] Clearly, demonstrating causation would be the greatest challenge to the compensation agreement. However, recent advances in modelling permit increasing confidence in probability distributions that particular weather events can be attributed to a variable such as climate change or climate engineering.[33] This is not to imply that this will be simple or clearly decisive, but only that it may be feasible. Finally, damages could be reduced or eliminated due to contributory negligence on the part of the victim. Expecting countries to prepare for harm from climate engineering research may initially seem unjust. Yet imagine a state with ineffective, perhaps unaccountable leadership who fails to devote adequate resources to natural disaster preparedness and basic infrastructure. A large scale SRM field trial induces a change in precipitation, causing severe harm. It seems inappropriate if such a state—or more likely, its leadership—were to then receive full compensation.

Depending on the degree of motivation among researching states to join, a multilateral compensation agreement for harm from climate engineering research could include commitments to research standards. These countries would be motivated to participate because the agreement would give them clarity of and limitations to their potential liability, and because it could give them political cover for a possibly controversial practice, particularly if states vulnerable to climate engineering harm were to participate also. If the researching states' motivation were great enough, then they could be asked in the agreement to commit to research standards such as state authorization of large scale field experiments, impact assessment, notification and consultation with potentially affected states, open publication of results, no prohibitive patents on SRM methods, public input in decision making, and international coordination. A further advantage of including standards is that, in the event that a researching state failed to fulfil these commitments for a field experiment which caused transboundary harm, then that state would be held liable for full or partial damages, with the compensation fund paying only residual damages.

[32] Eberhard Feess, Gerd Muehlheusser and Ansgar Wohlschlegel, 'Environmental Liability under Uncertain Causation' (2009) 28 Eur J Law Econ 133.

[33] Peter Stott and others, 'Attribution of Weather and Climate-Related Extreme Events' in Ghassem Asrar and James Hurrell (eds), *Climate Science for Serving Society: Research, Modeling and Prediction Priorities* (Springer 2013).

In order for the agreement to be effective, both researching states and potentially harmed states would need to participate. The motivations of the former are outlined above. The advantage for the latter to participate is clear: they would be compensated in the event of demonstrated harm. However, some very vulnerable states—especially those which are *not* at high risk of climate change itself—may decline participation because they would relinquish other means of pursuing compensation, and because participation could imply an implicit endorsement of a controversial activity which may harm them.

Finally, a compensation mechanism could also be expanded or developed separately for damages resulting from climate engineering implementation. However, the circumstances and incentives in that case will differ from those in the research context. It remains too early to make serious proposals for how countries, individually and collectively, may wish to use climate engineering.

4. NON-PROLIFERATION AGREEMENT

The fourth and most tentatively suggested component of regulatory regime for climate engineering and its research would be a non-proliferation agreement. This would be a tacit concession that countries now have and will continue to have divergent capabilities. To the extent that climate engineering becomes something which a given country does or does not have the capability to deploy globally or regionally, then a world with fewer such states would appear to be more stable and easier to manage than one with many more of them.

Although a non-proliferation agreement would primarily be intended to regulate climate engineering implementation, it would have some implications for research. An agreement could require those countries with the capability to implement climate engineering globally or regionally to cooperate with other states in research. This would both facilitate international cooperation and, by increasing the number of states with climate engineering expertise, foster transparency.

5. FINAL WORDS

I wish to close this dissertation with some brief editorializing. It is my sense that, as discussions over climate change became increasingly polarized in the 1990s and 2000s, those who were most concerned about climate risks became attached to and defensive of their proposed solution of aggressive abatement of greenhouse gas emissions. This is evident in the earlier resistance to adaptation as an additional set of responses.[34] Now, there is a similar opposition to the serious consideration of and research into climate engineering. This resistance may run deeper than that to adaptation, as climate engineering evokes a kind of mastery over nature and a rejection of 'the natural'. Both of these images run contrary to much of the original motivation of the environmental movement of the 1960s and 1970s.[35]

While I am sympathetic to these concerns, and indeed began this project dominated by them, I have come to fear that they are significantly impeding a reasoned evaluation of all options to reduce climate risks to humans and the environment. To me, these goals take primacy over the rejection of mastery over nature and the embrace of 'the natural'. This impedance can be seen in the tone of the majority of the climate engineering discourse, both mainstream and academic, including within legal scholarship. As I argued in the second article, the reviews thus far of applicable international environmental law have examined only the risks of climate engineering—without the context of its possible reduction of climate change risks—and have asked only how climate engineering activities may be restricted.[36] Even in the titles, the reviewers ask whether climate engineering may be 'the end of humanity' or enable 'continuing carbon addiction',[37] and rhetorically set it up as a straw man 'fix' or 'solution to climate change'[38]—something which no reasonable climate engineering research advocate has claimed it offers. I believe that environmentalist critics of climate engineering are 'more committed to their

[34] See the comparison of reactions to adaptation with those of climate engineering on p 18 of article 5, 'A Critical Examination of Climate Engineering Moral Hazard and Risk Compensation'.

[35] See text to n 30-33 in the Introduction.

[36] See text to n 99-100 in article 2, 'Climate Engineering Field Research: The Favorable Setting of International Environmental Law'.

[37] Catherine Redgwell, 'Geoengineering the Climate: Technological Solutions to Mitigation-Failure or Continuing Carbon Addiction?' (2011) 5 Carbon & Clim L Rev 178; Gerd Winter, 'Climate Engineering and International Law: Last Resort or the End of Humanity?' (2011) 20 Review of European Community AND International Environmental Law 277.

[38] Albert Lin, 'Geoengineering: A Technological Solution to Climate Change?' in (2011); Redgwell (n 37); Anthony E Chavez, 'Exclusive Rights to Saving the Planet: The Patenting of Geoengineering Inventions' Northwestern Journal of Technology and Intellectual Property, Forthcoming; Mike Hulme, *Can Science Fix Climate Change?* (Polity 2014).

answer to the problem than really thinking in what I feel is a morally clear way about what our duties are to this generation and reducing the risks that they feel.'[39]

This is unfortunate. Too much is at stake in climate change to approach a potential additional response, one which may significantly reduce risks, in this way. To be clear, I support only appropriately cautious climate engineering research, and remain agnostic on its eventual implementation. I also believe that, all things being equal, not causing a problem in the first place is preferable to addressing symptoms later. However, all things are not equal. Aggressive abatement will carry significant costs, including impeding economic development, and optimal abatement would still permit significant harm to humans and the environment while remaining unlikely to actually happen. I hope that my limited contributions to the discourse can help balance this bias which I perceive.

[39] David Keith interviewed by Michael Enright, 'Sunday Edition' (CBC Radio, 28 March 2014) < http://www.cbc.ca/news/technology/give-geoengineering-a-chance-to-fix-climate-change-david-keith-1.2586882> accessed 18 June 2014.